SOLID WASTE MANAGEMENT IMPLEMENTATION PROJECT

SAN FRANCISCO BAY AREA

Volume III

Technical Report on Levee Stabilization and Composting

ABAG ASSOCIATION OF BAY AREA GOVERNMENTS

BAY AREA SOLID WASTE MANAGEMENT IMPLEMENTATION PROJECT

VOLUME III

TECHNICAL REPORT ON LEVEE STABILIZATION AND COMPOSTING

A Report Prepared for the Action Committee for the Bay Delta Resource Recovery Demonstration and the Association of Bay Area Governments

December 1973 by

ENVIRONMENTAL IMPACT
PLANNING CORPORATION
SAN FRANCISCO, CALIF.

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In association with Frank Stead

ABAG ASSOCIATION OF BAY AREA GOVERNMENTS

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16. Abstracts This document is Volume III of a three-part report to ABAG. This report documents the planning conducted for the Bay Delta Resource Recovery Demonstration project. This proposed project would demonstrate recovery of resources from urban wastes and the use of composted refuse for island reclamation in the Sacramento-San Joaquin Delta. The report presents original research on the use of compost as a levee strengthening material and documents the planning for an intergovernmental structure to manage the demonstration, and serve as a first step towards eventual regional management of solid wastes. The report is published in three volumes, as follows:

Vol. I: Project Report
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December 14, 1973

Mr. Revan A. F. Tranter
Executive Director
Association of Bay Area Governments
Claremont Hotel
Berkeley, California 94705

Dear Mr. Tranter:

In the fall of 1972 a group of local agencies in the San Francisco Bay Area joined together in an attempt to initiate a Demonstration project to test the feasibility of using composted organic solid wastes in the low-lying islands of the Sacramento-San Joaquin Delta for levee stabilization, land building and agricultural purposes. These local agencies, calling themselves the Bay Delta Resource Recovery Action Committee, also sought to develop the intergovernmental institution necessary to manage this Demonstration project and perhaps to become the regional agency charged with solid waste management. This report documents the efforts of these local entities, acting voluntarily, to attempt to improve the technical and governmental mechanisms operating in the field of solid waste management today.

The report is presented in three volumes. Volume 1 describes the preliminary system design for the Demonstration project and looks at the concept of Bay-area wide implementation of the plan. It also details the possible institutional mechanisms necessary to implement the plan. Volume 2 is an environmental evaluation of the Demonstration project and is written in the format of an Environmental Impact Report. Volume 3 contains two technical reports upon which the preliminary system design was based. Part A is a study of the structural characteristics of compost and an evaluation of the feasibility of using compost as a levee strengthening material. This report, prepared by Drs. Duncan and Seed of the Engineering Department of the University of California, Berkeley, represents original research on this subject. Part B documents the preliminary compost experiment conducted by Dr. Samuel Hart at Davis, California, and includes recommended composting specifications for the Demonstration.

The consultants wish to thank the members of the Action Committee and its chairman, Councilman Fred Maggiora, for making this report possible. We would also like to thank the U.S. Army Corps of Engineers (San Francisco and Sacramento Districts), the

Mr. Revan A. F. Tranter
December 14, 1973
Page 2

California Department of Water Resources, the Central Valley Regional Water Quality Control Board, and the California Water Resources Control Board for their valuable contributions. Further, we would like to thank the Sierra Club, the League of Women Voters and the San Francisco Planning and Urban Renewal Association, as well as the many public and private organizations and individuals who participated in this study.

Yours very truly,

Hans A. Feibusch, P.E. and Frank M. Stead

TABLE OF CONTENTS

PART A

A STUDY OF THE FEASIBILITY OF STABILIZING DELTA LEVEES WITH A BERM OF COMPOSTED MUNICIPAL WASTE

by

J. M. Duncan and H. Bolton Seed
with an appendix by Celso Ugas

Purpose of Report

This report presents the results of our study of the feasibility of stabilizing delta levees with a berm of composted municipal waste or a mixture of composted municipal waste and dredger spoils. Our study has been concerned with evaluating (1) the mechanism of stabilization and effectiveness of a compost berm, (2) the effects of a compost berm on the seepage, settlement, and stability of the levee and the land adjacent to the levee, and (3) the construction problems which can be anticipated on the basis of previously reported experience in filling over the peat lands of the California Delta.

The study included a program of laboratory tests to determine the density, compressibility, permeability and shear strength of the compost material. Information on the soil conditions in the Delta was obtained from published papers and reports, from discussions with the personnel of the California Department of Water Resources and the U. S. Army Corps of Engineers, and from discussions with other people knowledgeable and experienced in Delta soil and levee problems.

The study is concerned with the feasibility of the stabilization program in general, rather than its application to a particular site. It is believed that the conclusions and recommendations will be applicable to most sites in the Delta. If a particular site is selected for further study, however, test borings will be required to evaluate the soil conditions at the site. In addition, a program of field observations should be undertaken during any field test to make a closer evaluation of settlements, seepage conditions, and safety.

Present Conditions of the Levees

There are 1100 miles of levees in the Delta. The manner of their construction and present conditions vary widely. A cross-section through a levee depicting conditions typical of many sites in the central Delta is shown in Fig. 1. As indicated in this figure, the crests of most sections of the levees are about 10 ft. above sea level. The highest water level expected in 100 years is about 7.5 ft. above sea level throughout most of

the central Delta. The island floor elevations vary from island to island and from place to place on each island. At most locations in the central Delta the elevations of the island floor vary from sea level to 20 ft. below sea level. The widths of the levees and the steepness of the levee slopes also vary considerably from place to place.

Many sections of the levees have been constructed of several different types of fill. These include sands, silts, clays, and peat. When these soils were placed on the peat subsoil, the peat compressed, and a large portion of the fill settled into the peat. At many locations the levee has settled so much that less than half of the fill now protrudes above the original level of the top of the peat.

The thickness of the peat subsoil varies throughout the Delta, reaching a maximum in excess of 50 ft. in a few small areas. In a large area of the central Delta its thickness is 30 ft. or more. Beneath the peat there is usually a thin layer of peaty silt or clay, and beneath that a layer of sand. The grain size of the sand varies from fine to coarse, and in places there are even zones of gravel. The water in the sand is normally under artesian pressure, and would rise in a standpipe above the level of the island floor. The water level in the peat is maintained at or below ground level by networks of irrigation and drainage ditches. Because the head of the water in the sand is higher than in the peat, water seeps upward steadily through the peat and must be pumped over the levees to keep the water level below the island floor. Water also seeps through the levees, especially in sections where they are built of sand.

Problems of Levee Performance

A. Seeping Water Erodes Soils and Weakens Levees. A widespread problem in the Delta is the erosion caused by water seeping through and under the levees. Where the seepage is concentrated in zones of permeable soils or cracks, the flow velocities may be sufficient to dislodge and erode soil particles, as shown in the upper part of Fig. 2. If erosion is allowed to continue, the condition will grow steadily worse. An advanced stage of erosion, with an eroded "pipe" having formed under the levee, is shown in the lower part of Fig. 2. Such a pipe will continue to work its way backward under the levee

until the weight of the overlying soil is great enough to cause the pipe to collapse. Then a portion of the levee slope may collapse into the pipe, forming a sinkhole. Collapse is most likely to occur where the levee slope is already cracked, as are the landside slopes in some locations. These cracks are probably the result of differential settlement of the levee. We believe that this is the mechanism by which sinkholes form in the landsides of levees during high water periods. The cracks and the erosion greatly weaken the levee, essentially removing the support of the landside of the levee in the area of erosion.

B. Weakened Sections Can Fail During High Water. A rise in the water level has two dangerous effects on this weakened section of the levee. First, the water pressures in the remaining stable portion of the levee increase. The increased water pressure on the base of this section tends, in effect, to float it up out of position. At the same time, during high water, the horizontal thrust of the water increases. Eventually, when the water is high enough and exerts enough force on the levee, the weakened section may be shoved inward, as shown in Fig. 3, causing a breach in the levee and flooding of the island. These mechanisms of failure appear to be consistent with accounts of the events leading up to levee failures and the movements observed during failures, and it is believed that these mechanisms were probably operative in many of the more than 50 levee failures which have occurred since 1900.

C. Gradual Settlement Requires Continued Building to Maintain the Grade of the Levees. The spongy peat soils beneath the levees not only settle a large amount during the time when fill is being placed on them, but they also continue to settle over a long period of time thereafter. Consequently, the levees built on peat are settling continually at rates up to 6 inches per year. This settlement must be compensated for by regularly placing more fill on the levees to keep their crests high enough to afford the required protection against flooding.

The magnitudes of the settlements of fills on peat are shown in Fig. 3. This chart was developed using data compiled by the California Department of Water Resources and the U. S. Army Corps of Engineers. The chart relates

the settlements due to compression of a 30 ft. thick layer of peat to the increase in effective stress due to the weight of the fill. The increase in effective stress is equal to the thickness of the fill multiplied by the moist density of the fill material if the fill is above water. If the fill is below water, the increase in effective stress is equal to the fill thickness multiplied by the buoyant density of the fill.

As an example, consider 5 ft. of sand fill placed on a 30 ft. thick peat layer. As shown in the table at the top of Fig. 4, if the fill were above water, the increase in effective stress would be 550 psf, and the settlement would be about 9.3 ft. In fact, if the fill settled 9.3 ft. it would be entirely below water, because the water table is very near ground level in the peat. Assuming that the entire 5 ft. of fill was under water, the increase in effective stress would be 250 psf and the settlement would be about 4.4 ft. Depending on the exact position of the water table, nearly the entire 5 ft. of sand fill would sink into the peat.

If a lighter fill material was placed on the peat, the increase in effective stress and the resulting settlement would be smaller. A 5 ft. layer of compost placed on a 30 ft. thick layer of peat would settle about 2.8 ft.

The settlements due to compression of peat layers are approximately proportional to the thickness of the layer. Fig. 4 may be used to calculate settlements due to compression of peat layers of other thicknesses by correcting the settlement in proportion to the thickness of the layer.

D. <u>Subsidence of Island Floors is Gradually Increasing the Levee Heights and Water Head Differentials</u>. Perhaps the most significant Delta problem in the long run will prove to be the fact that the island floors are gradually subsiding. Data are shown in Fig. 5 for three Delta islands, which indicate average subsidence rates of about 2.5 inches to 3 inches per year over a period of more than 40 years (Weir, 1971). The greatest part of this subsidence (about 80%) is believed to be due to oxidation of the organic peat soils where they are permitted to become dry at the ground surface (Winslow, 1973). The remainder is attributed to burning of the peat, settlement due to compression of the peat, and deep-seated settlement.

As this subsidence occurs, the island floors drop farther and farther below the crests of the levees, increasing the effective heights of the levees. The water head differential across the levees thus also increases, and the levees are subjected to continually increasing water loads. This increases the likelihood of failure in weak sections of the levees. The water load increases in proportion to the square of the head differential across the levee, and a levee with a 20 ft. differential must withstand a load four times as great as a levee with a 10 ft. differential.

E. Soft Peat Soils Make Construction Difficult. The Delta peat soils are not only very compressible, they are also very weak. Heavily loaded trucks and other equipment can break through the stronger crust at the surface and bog down in the peat. Rapid filling on the peat can result in the fill material breaking through the surface of the peat if the fill is piled too high or the slopes are too steep. To build high fills on the peat it is necessary to increase the thickness of the fill gradually, allowing the peat to compress and gain strength under the added load.

Properties of Compost and Mixture of Sand and Compost

The appendix to this report contains the results of a program of laboratory tests performed by Mr. Celso Ugas, a graduate student at the University of California, to determine the properties of the compost and a mixture of equal parts (by weight) of compost and sand.

The compost tested was prepared by Dr. Samuel A. Hart,* and is considered to be representative of the type of material which will be produced by the full-scale composting of municipal wastes. The material is dark brown when wet and has the appearance of leaf mulch. The largest particles in the sample received were about 3/8 inch and the finest were fine sand size. The specific gravity of the solid particles is very low, probably close to unity. The sand mixed with the compost for some of the tests was a fine, uniform river sand dredged from the Sacramento River.

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*The results of tests on an older compost are described in Appendix B.

A. Compaction Characteristics and Densities. Particulate materials such as soils and compost do not have a single characteristic density. Depending on the amount of effort expended in compacting them, and the amount of water they contain when compacted, they can have a wide range of densities.

To determine what densities the compost and the mixture of compost and sand might be compacted to in the field, these materials were subjected to the Standard AASHO compaction test in the laboratory. This test was devised to simulate the best compaction achievable with light rollers in the field. Experience with clay soils indicates that compaction with a small bulldozer produces lighter pressures and lower densities, on the order of 85% to 90% of the values achievable in the Standard AASHO test. It is assumed that the same would be true for the compost or the mixture of sand and compost.

The results of the compaction tests are shown in Fig. 6. In this figure the dry densities of the materials have been plotted against the water contents during compaction. The dry unit weight is the weight of solids divided by the volume of the sample, and is thus a measure of the amount of solid material per unit volume. It can be seen that the densities of both materials first increase and then decrease with increasing water content. The maximum dry densities are 39 lb/ft^3 for the compost and 57 lb/ft^3 for the mixture of compost and sand. The optimum water contents (the water contents which produce the maximum densities) are 75% for the compost and 50% for the mixture. These water contents are expressed in percent of the dry weights.

If the compost were compacted in the field to 85% of its maximum density in the Standard AASHO tests, its dry density would be 33 lb/ft^3. Even if the material were compacted at the optimum water content its voids would not be filled with water, and the water content of the material could increase as it absorbed additional water from rainfall or irrigation. If the water content reached 100%, which seems possible, the moist density of the material would be 66 lb/ft^3. We have assumed in our studies that the moist density of the compost in the field will be 65 lb/ft^3. This value should be checked by field measurements if a test section of berm is built.

If the mixture of compost and sand was compacted to 85% of the maximum, its dry density would be 48 lb/ft^3. If its water content subsequently increased to 75%, the moist unit weight would be 85 lb/ft^3, or 19 lb/ft^3 greater than the anticipated moist density of the compost without sand. Because settlements are smaller and stability problems less if the fill is lighter, it would thus be advantageous from the point of view of density to use the compost by itself with no sand added.

B. Compressibility. If the compacted compost is subjected to pressure it will compress. The lower part of the fill in the berm, for example, will compress under the weight of the overlying material. The amount of compression depends on the density and the applied pressure. The results in Fig. 7 show that at the base of a 16 ft. deep fill with a moist density of 65 lb/ft^3, the compost would compress about 14%. The average compression for the whole thickness of the fill would be less, about 9%. Although these amounts of compression are quite large compared to the compression of most soils, they are not very large compared to the compression of the peat. Because large settlements will occur due to compression of the peat, the settlements due to compression of the compost do not appear to be a cause for much concern.

At the same percentage of maximum dry density, the mixture of compost and sand compressed somewhat less than the compost without sand, but the difference was not very large. Based on considerations of compressibility, there would be little benefit from mixing sand with the compost.

C. Permeability. The results of falling-head permeability tests on the compost and the compost-sand mixture are shown in Fig. 8. The permeabilities of both materials vary considerably with density. In addition, the permeability of the compost appears to be affected appreciably by the compaction water content. All specimens were saturated when tested, and it appears that the effect of the water content must be due to some difference in the arrangement of the compost particles. Why there is not a similar effect in the case of the compost-sand mixture is not clear.

It is desirable that the permeability of the fill in the stabilizing berm should be as high as possible. The results in Fig. 8 indicate that adding

sand to the compost does not increase its permeability greatly, and consequently there is no great advantage from the standpoint of permeability, from mixing sand with the compost for construction purposes.

The permeability values shown in Fig. 8 range from 5×10^{-5} cm/sec to 10^{-2} cm/sec. These values are comparable to the permeabilities of fine sands and silty sands (10^{-1} cm/sec to 10^{-5} cm/sec) and are generally greater than the permeability of peat (5×10^{-5} cm/sec to 10^{-7} cm/sec depending on how much the peat has been compressed). The values shown in Fig. 8 are values of vertical permeability. Owing to the fact that the compost contains many sheet-shaped pieces which tend to assume horizontal orientations during compaction, it is believed that the horizontal permeability would be higher, though how much higher is not known. In-situ tests to measure the permeability of the compost should be performed during any field test program.

D. Shear Strength. Drained direct shear tests were performed to determine the shear strength characteristics of the compost and the mixture of compost and sand. The results of some of these tests are shown in Fig. 9. The strength of both materials increased with increasing normal stress and density. Both materials exhibited friction angles comparable to those of sands at medium densities and appreciable amounts of cohesion, apparently from overlapping and interlocking of particles. It should be remembered, however, that these materials are quite compressible, and quite large movements would be required to mobilize their full strengths.

Only the drained strengths of the materials were measured because their permeabilities are high enough to conclude that they will be able to drain freely during construction. Furthermore, in their partly saturated condition after filling, the drained and undrained strengths should be the same for all practical purposes.

Because the compost and the mixture of compost and sand have very similar strength and compressibility characteristics, and because both appear to have fully adequate strength for use in a stabilizing berm, there is no advantage with regard to strength to be achieved by mixing sand with the compost.

E. Filter Performance. In order to determine if the compost material was capable of acting as a filter for silts and sands, a test was performed in which an attempt was made to wash a silty material through a thin layer of compost. No silt was washed through the compost, indicating that the compost can serve as a filter for fine-grained soils.

F. Conclusion Regarding the Benefits of Mixing Sand with the Compost. The tests performed showed that mixing sand with the compost increases its density but has little effect on its compressibility, permeability and strength. Because increased density is not desirable, it is concluded that it will be better not to mix sand with the compost if it is to be used for construction of a berm behind the levees.

Effects of Constructing a Compost Berm

The berm considered in this report would be built with a uniform slope of 25 horizontal to 1 vertical from the crest of the levee to the island floor. For a levee 20 ft. high, the berm would extend 500 ft. inland from the levee crest.

A. Stabilization Against Erosion. One of the most effective methods of preventing erosion of soil by seeping water is to provide a "weighted filter drain" at the point where the water discharges from the ground. The filter drain allows the water to pass freely, but prevents the soil from moving. If the compost were more permeable than all of the soils beneath it, it would perform as a weighted filter drain by itself, with no need for additional drains. The test data indicate that the compost is probably more permeable than the peat, but it may be less permeable than the sandy soils in the levees. Therefore it will be necessary to provide a drainage system beneath the berm to be sure that no appreciable water pressures can build up beneath the berm where seepage emerges from the levee fills.

One means for providing good drainage is shown in Fig. 10. The drainage system consists of a number of ditches containing perforated drain pipes surrounded by gravel and filter material. The pipe should be capable of carrying a flow of 0.1 ft^3 per minute with a hydraulic gradient (or slope

of the hydraulic grade line) equal to 0.007. The pipe should be surrounded with clean fine gravel, and the gravel should be surrounded by a clean sand which satisfies normal filter requirements with respect to the soil in which the drain is constructed, so that the soil will not be washed into the drain and plug it. The ditches should be a minimum 4 ft. deep and 1.5 ft. wide. One ditch runs parallel to the levee, as close to the toe as it can be conveniently constructed, and not more than about 20 ft. from the toe. This ditch connects to the other ditches, spaced at intervals of 100 ft., running in the perpendicular direction. Beyond the point where the ditches emerge from beneath the compost berm, they are open, connecting eventually with the existing ditches on the island.

Additional drains should be installed where it is known that seepage emerges from the levee slope when the river level is high. In these places, drains should be built extending from the toe drain up the slope to the area where the water emerges. Additional drains should also be built where there are springs or wet spots in the peat within the area to be covered by the berm. Drains should be built leading from the wet spot to the closest drain.

Any other drainage system providing equal drainage capacity and pressure relief could also be used. A two-foot thick uniform blanket of sand with a permeability of at least 10^{-2} cm/sec would provide the required drainage. It would have the advantage of not requiring disruption of the surface of the peat, but would have the disadvantage that its greater weight would cause more settlement. We believe that the capacity of these drains will be sufficient to carry away the water seeping horizontally through the levee and vertically upward through the peat without permitting dangerous pressures to build up beneath the berm. An adequate system of drains will provide improved safety against erosion and weakening of the levees. We consider provision of features for drainage and erosion control to be essential, because increased water pressures would endanger the stability of the levee, and because erosion beneath the berm would be difficult or impossible to detect and might progress to the point of catastrophic failure without any externally detectable signs.

B. Stabilization Against Catastrophic Levee Failure. Providing adequate filter drains to prevent erosion will also prevent the associated weakening of the levees. In addition, the berm would provide weight and strength to buttress the levee against the high water forces. In order to provide sufficiently high strength and low compressibility to perform effectively as a buttress, the compost should be compacted to a reasonably good density, on the order of 90% of the maximum dry density in the Standard AASHO Compaction Test.

Eventually, after the berm has been constructed, it will be possible to increase the height of the levee with less risk of failure than is now possible. The higher levee will provide increased safety against overtopping and additional weight to resist uplift at high water level. The berm will not affect the stability of the levee with respect to failure of the water-side slope.

C. Settlement, Cracking, and Loss of Freeboard. Placing the berm behind the levee will cause settlement due to compression of the underlying peat. This settlement will be greatest in the region of the toe of the levee, where the height of the berm is greatest. The weight of the berm will also cause some settlement of the levee itself.

The amount of settlement which would result from construction of a compost berm has been calculated for the conditions shown in Fig. 1, using the settlement data shown in Fig. 4. The results of the calculations are presented in Fig. 11. The calculated settlements increase from 0.8 ft. at the levee centerline to a maximum of about 8 ft. at the levee toe, and then decreased to zero at the toe of the berm. These calculations are based on an assumed peat thickness of 30 ft. and a berm 16 ft. high at the toe of the levee. The settlements would be smaller if the peat thickness was less than 30 ft. or if the berm thickness were less than 16 ft. Conversely, if the peat were thicker or the berm higher, the settlements would be proportionately greater.

The settlements indicated in Fig. 4 and Fig. 11 are long-term settlements. Experience with fills on peats in the Delta indicates that about half of the settlement will have taken place by the time the fill has been placed,

provided that filling takes 3 months or more. The remaining settlement will take place over a period of years, with about 70% of the total occurring after 3 years, and 90% after 30 years. Settlements would continue even after 30 years, but at a greatly reduced rate.

These nonuniform settlements will cause the levee to crack, as shown in Fig. 12. With the water side of the levee settling less than a foot and the landside toe of the levee settling 8 ft., the levee will be split open at the top. The result might be a single crack as shown in Fig. 12, or a series of cracks. They may be located at the crest of the levee or on the inside slope. They would be expected to be generally parallel to the longitudinal axis of the levee, but they could conceivably cross the axis at a small angle, depending on the locations of the weakest soils in the levee.

This is the most dangerous consequence of building the berm. The cracks, if left unrepaired, could endanger the levee in a number of ways. First, if the cracks crossed the levee diagonally, they could form paths for serious leakage through the levees and flows of high enough velocity to cause dangerous erosion. Second, the levee fill would eventually collapse into the open cracks, resulting in extensive deterioration and weakening of the levees. In addition, wide cracks would disrupt the levee roads and make driving on them dangerous or impossible.

There does not appear to be any feasible way of preventing the nonuniform settlement or the associated cracking. A procedure for repairing the cracks might be developed, but there are some serious difficulties which must be faced: If the cracks were filled with soil it would be difficult to insure that the bottom of the crack was filled, and it would not be possible to compact the soil except near the surface. Any method of repair would have to be repeated, because the settlement will continue over a long time, and the cracks can be expected to reopen as the settlement continues. Cracks developing on the levee slope after the berm is complete would not be visible, because the slope will be covered by the berm. Unless the cracks extend up through the compost berm, they will not be seen.

The drain at the toe of the levee will settle as the ground surface settles in that location and will eventually be eight feet below its original elevation. The perpendicular drains will also settle and will eventually slope upward from the levee toe drain to the edge of the compost berm. Under this condition the drains will be filled with water under pressure all the time. The head levels in the drains should remain unchanged, however, and they should function as well after having settled as they did before.

To maintain the present freeboard, it would be necessary to build up the levee to compensate for the settlement. The berm would increase the stability of the levee with respect to failures due to the water load and failures toward the inside. The berm would not affect the stability of the water-side slope, but increasing the height would tend to make this slope less stable. To minimize this, it would be desirable to increase the height of the levee by placing the added fill so that the water-side slope is not made steeper as the crest is raised.

Summary of Effects of Using a Compost Berm

The benefits to be derived from building a compost berm behind the levees are: (1) The berm will provide increased stability on the land-side slope of the levee, and (2) To construct the berm it is essential first to install a system of filter drains. These drains will provide a good measure of control over erosion.

The detrimental effects of a berm are: (1) It will cause non-uniform settlement of the levee which will result in cracking. These cracks will be difficult to repair and cracking can be expected to continue over a period of years. (2) Settlement will result in some loss of freeboard and it will be necessary to add fill to the tops of the levees to maintain the present freeboard. This added height will reduce the stability of the water side slopes.

Because the island floors are subsiding and the differential water head on the levees is increasing, it will be necessary eventually to strengthen the levees. Constructing a berm adjacent to the levees appears to be perhaps the best method of strengthening them, and the berm could be built

of either mineral soil or compost. As compared to mineral soils, compost is lighter, and the same depth of fill would cause less settlement. On the other hand, mineral soils are stronger than compost, and equal buttressing effect could probably be achieved with a lower and less extensive berm. Therefore there appears to be little to choose between mineral soil and compost as berm materials on the basis of their engineering properties. It appears at the present time that, if a berm is to be built, it may as well be built of compost.

Construction Procedures

The U. S. Army Corps of Engineers (1944, 1960), the California Department of Water Resources (1963), and Weber (1969), have summarized the lessons learned from many years of experience in placing fills on peat soils in the Delta. Careful attention to these lessons will undoubtedly result in reduced costs and greater success in any future construction operations. These lessons include the following:

(1) The peat cannot support heavy equipment. 12-ton trucks broke through the peat on the second or third pass over the same area. Small crawler tractors can move on the peat without breaking through.

(2) High fills, rapidly built, will cause failure of the peat. Fills exerting loads of about 500 psf can usually be built fairly rapidly without causing failure, but higher fills should be built slowly enough so that the load increase is no more than about 50 psf to 100 psf per week. With slow filling rates and gentle slopes, there should be no trouble in building a fill exerting a pressure of 1000 psf.

(3) The strong surface layer of the peat should not be disrupted. No clearing or grubbing should be done, except for removing trees and heavy brush. It would be more desirable to burn off heavy grass than to strip it. Where the surface of the peat must be broken, as for example for construction of drains, procedures should be used which minimize the disturbance.

(4) Construction on the peat should be limited to the dry season. It may be possible to continue construction of the berm throughout the year

by doing all the work that needs to be done directly on the peat during the dry summer months. With drains installed and the bottom 4 or 5 ft. of compost placed in the summer, perhaps the compost filling operations can be continued through the winter.

Further Studies Required

This study indicates that a compost berm probably would have a beneficial stabilizing effect on the Delta levees provided that effective procedures can be found for dealing with the problems caused by the cracking of the levees due to nonuniform settlements. This is, however, only a preliminary study. The best methods of dealing with the cracking problem and other important questions will require further studies in the field. When a particular site has been selected, a topographic survey, test borings and a thorough reconnaisance should be made at the site. The conditions at the site should be compared to those assumed in this feasibility study to determine the applicability of the results of this study to the site selected. If portions of this study are inapplicable to the actual conditions at the selected site, additional studies will be required.

If it is decided to construct a test berm the following studies should be undertaken:

(1) Settlements, horizontal movements, and spreading of the levee crest should be monitored carefully during the entire project. Construction should be halted if the settlements exceeds those predicted or if the lateral movement of the water side of the levee crest exceed 0.5 ft. Construction should only be resumed if a careful study indicates that failure of the levee is not impending.

(2) A thorough program of crack surveillance and repair should be conducted continually during construction and after construction. The best method for detecting and repairing cracks will require further study before and during construction, but it is clear that extensive cracking could weaken the levees considerably, and this matter will require very careful attention.

(3) Piezometric levels in the drains and in the peat beneath the berm should be observed to ensure that the water pressures are in fact maintained at low, safe levels by the drainage system.

(4) Densities and water contents of the compost should be measured on a regular basis, and supervision should be provided to ensure that the densities measured are representative of the entire fill.

(5) In-situ permeability tests should be performed in the peat, the compost and the drain materials using the falling head permeability procedure with standpipe piezometers.

(6) The settlements at the toe of the levee should be monitored to check the accuracy of the method of predicting settlements.

Many important questions can be answered only by performing field studies. These include:

(1) Can an effective program of crack surveillance and repair be developed so that the berm can be built safely?

(2) What is the best type of equipment for handling the compost?

(3) Will it be necessary to wet the compost or dry it out to improve compaction?

(4) Will the surface of the compost tend to dry out and become subject to wind erosion? If so, how can this be prevented?

(5) Can procedures be developed so that construction can continue in the wet winter months?

The test fill program, if undertaken, should be planned so that these questions are answered at the earliest possible stage.

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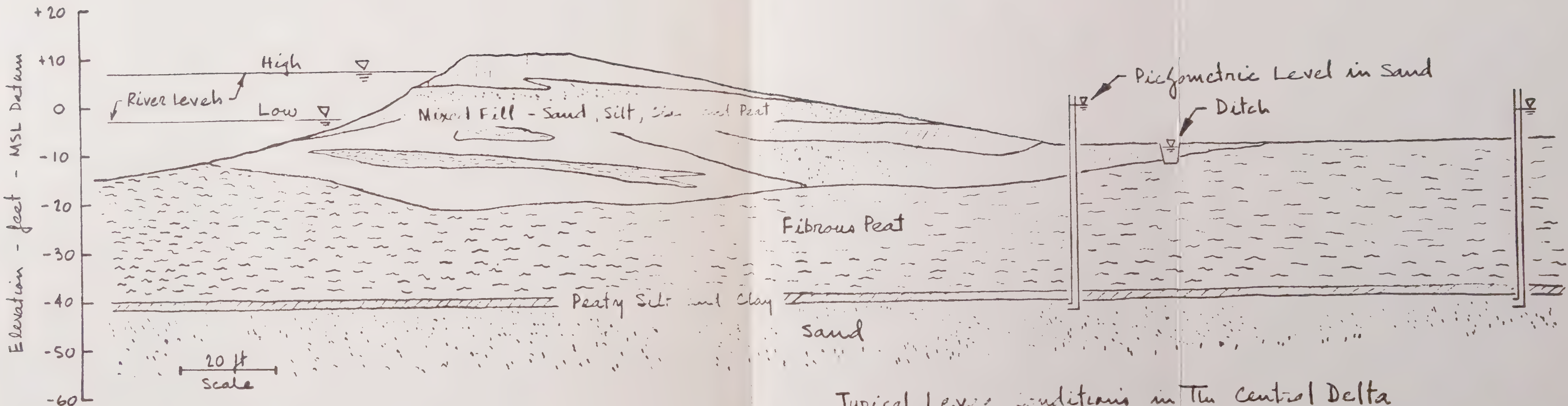
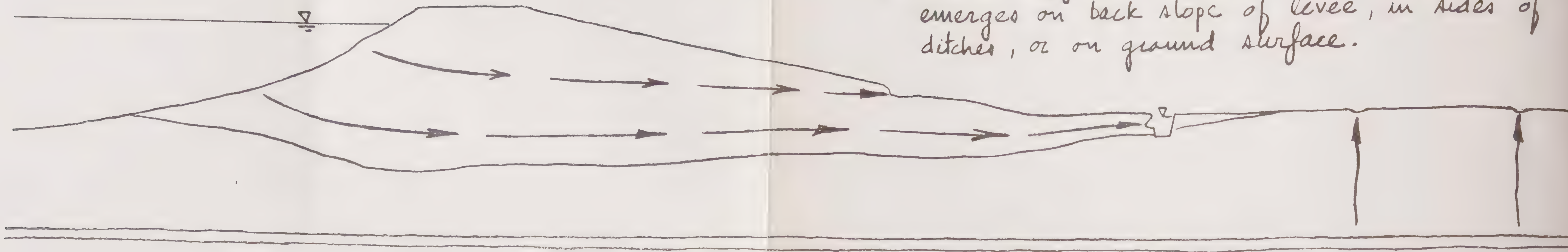


Typical Levee Conditions in The Central Delta

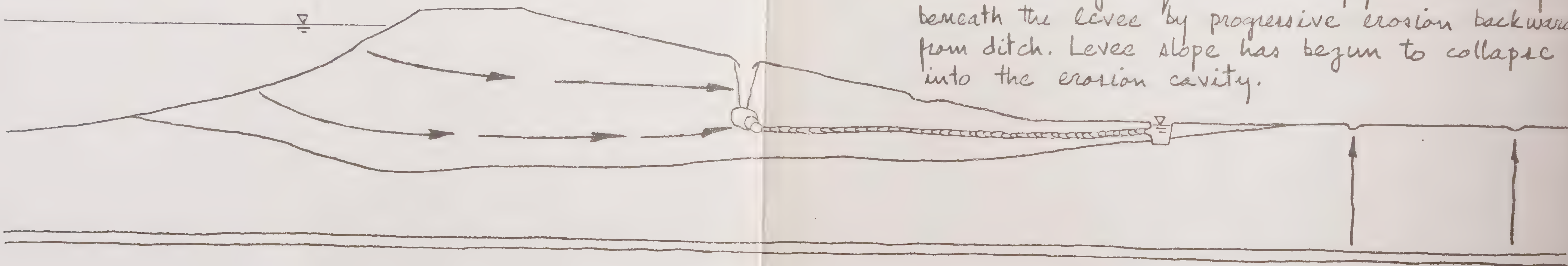
Compiled from Department of Water Resources and Corps of Engineers Data

Figure 1

A. Erosion begins at points where seeping water emerges on back slope of levee, in sides of ditches, or on ground surface.



B. Advanced stage of erosion. A "pipe" has developed beneath the levee by progressive erosion backward from ditch. Levee slope has begun to collapse into the erosion cavity.

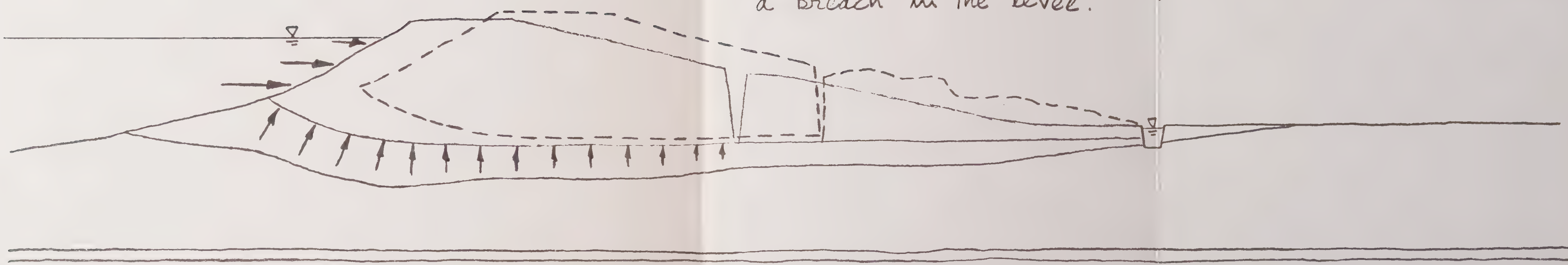


Mechanics of Erosion and Piping in Levees

Figure 2

Events leading to levee failure:

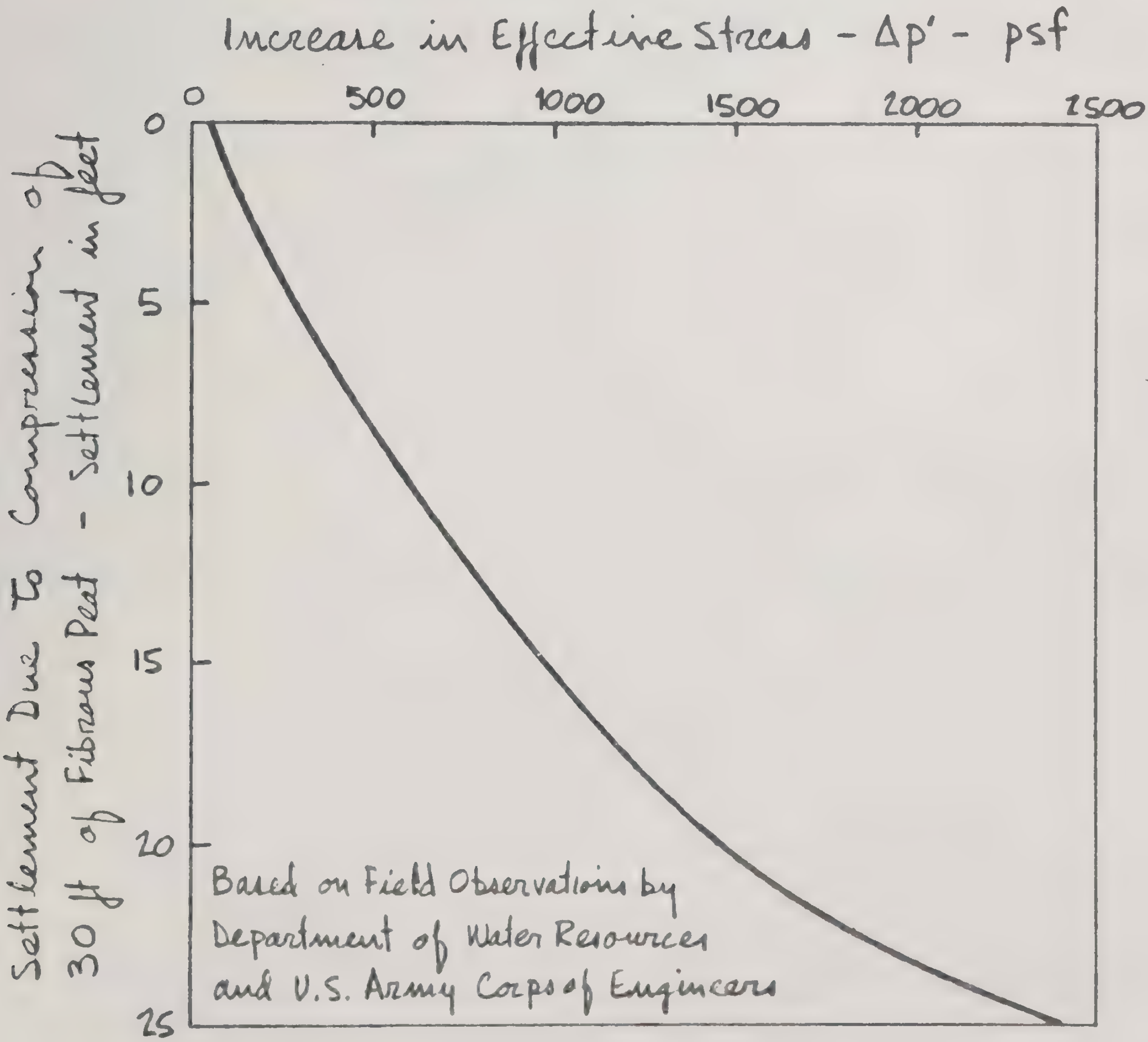
1. Erosion and piping weaken landward side of the levee.
2. Uplift pressure increases due to higher water level, tending to float the water side of the levee out of position.
3. Horizontal thrust from water increases as water level rises, and finally shoves a section of the levee inward, forming a breach in the levee.



Mechanism of Levee Failure

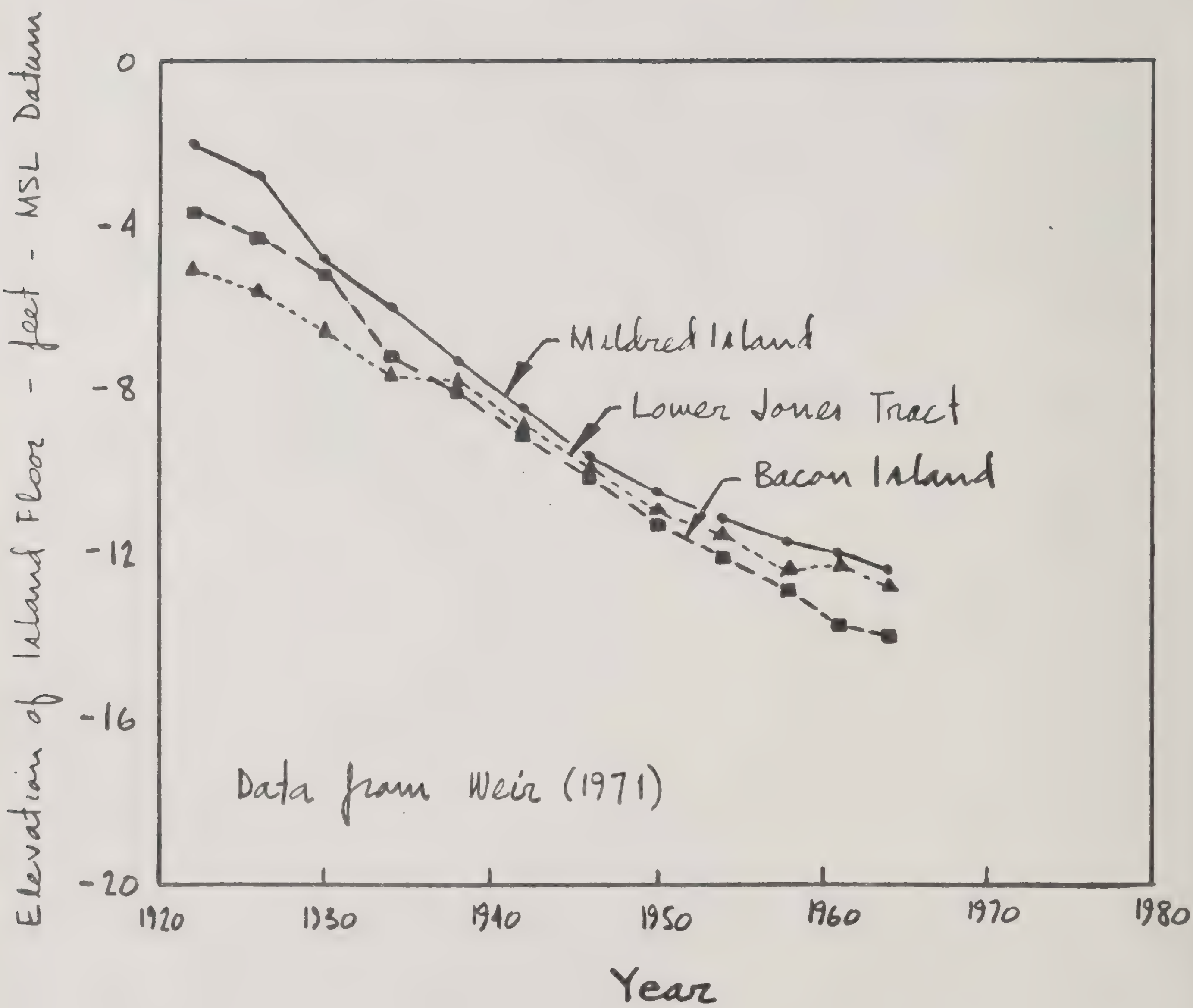
Figure 3

Type of Fill	Thickness of Fill 5 ft	10 ft	15 ft	20 ft
Sands and Silts above water	$\Delta p' = 550$ psf	$\Delta p' = 1100$ psf	$\Delta p' = 1650$ psf	$\Delta p' = 2200$ psf
Sands and Silts below water	$\Delta p' = 250$ psf	$\Delta p' = 500$ psf	$\Delta p' = 750$ psf	$\Delta p' = 1000$ psf
Compost above water	$\Delta p' = 325$ psf	$\Delta p' = 650$ psf	$\Delta p' = 975$ psf	$\Delta p' = 1300$ psf
Compost below water	$\Delta p' = 25$ ps	$\Delta p' = 50$ psf	$\Delta p' = 75$ psf	$\Delta p' = 100$ psf



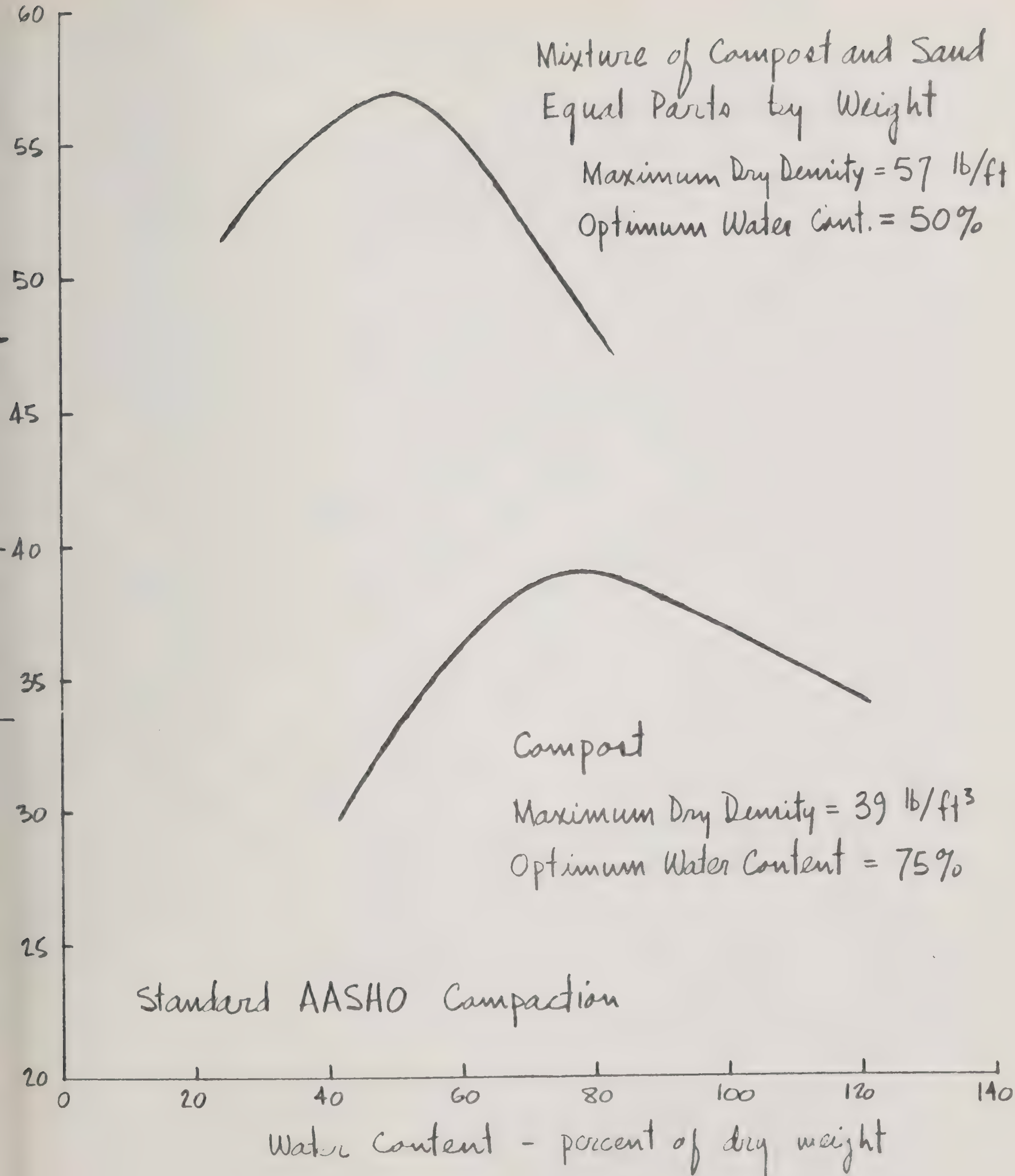
Settlement of Fills Placed on Fibrous Peat

Figure 4



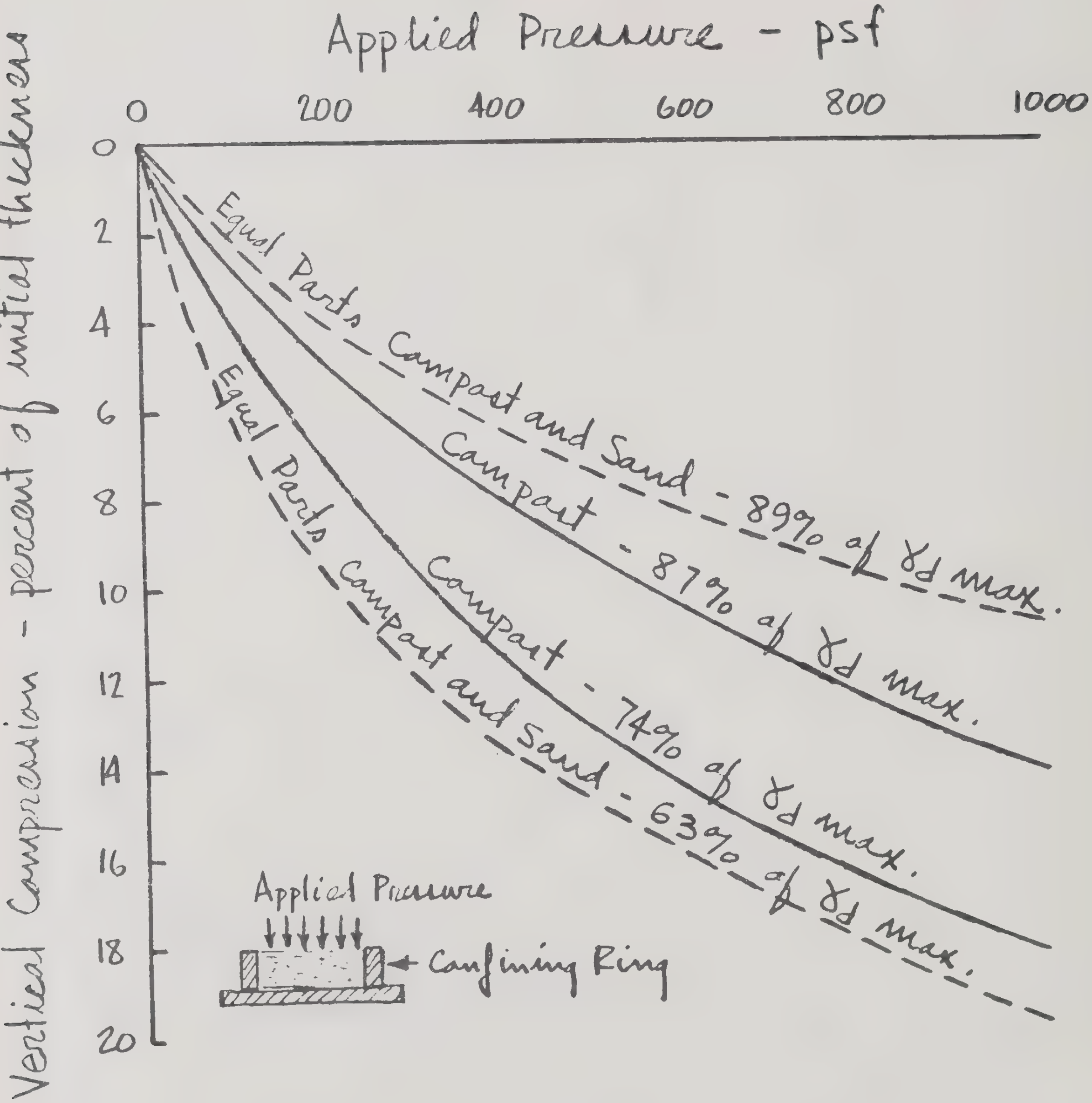
Gradual Subsidence of Three Delta Islands

Figure 5



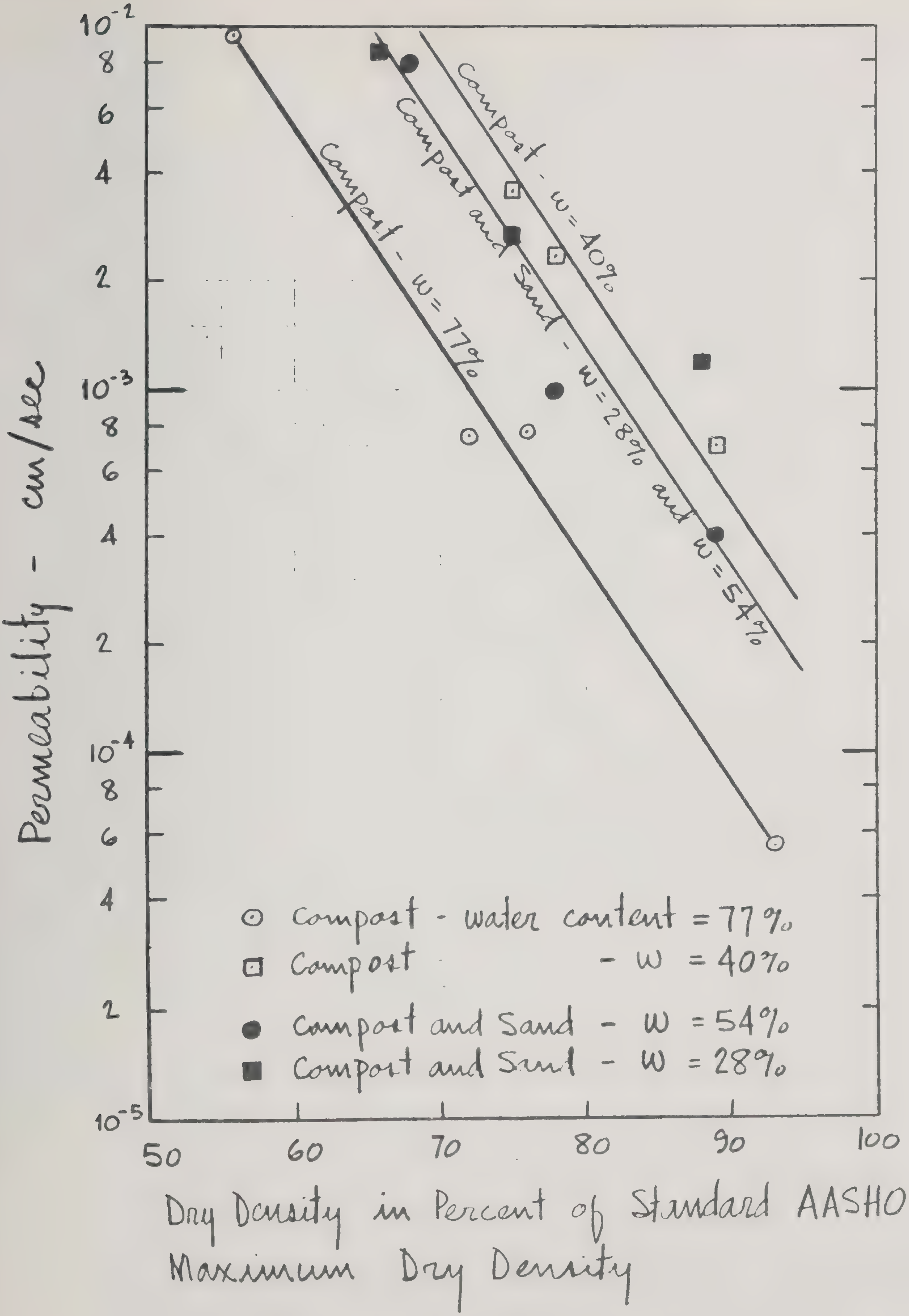
Compaction Characteristics of Compost and Mixture of Compost and Sand

Figure 6



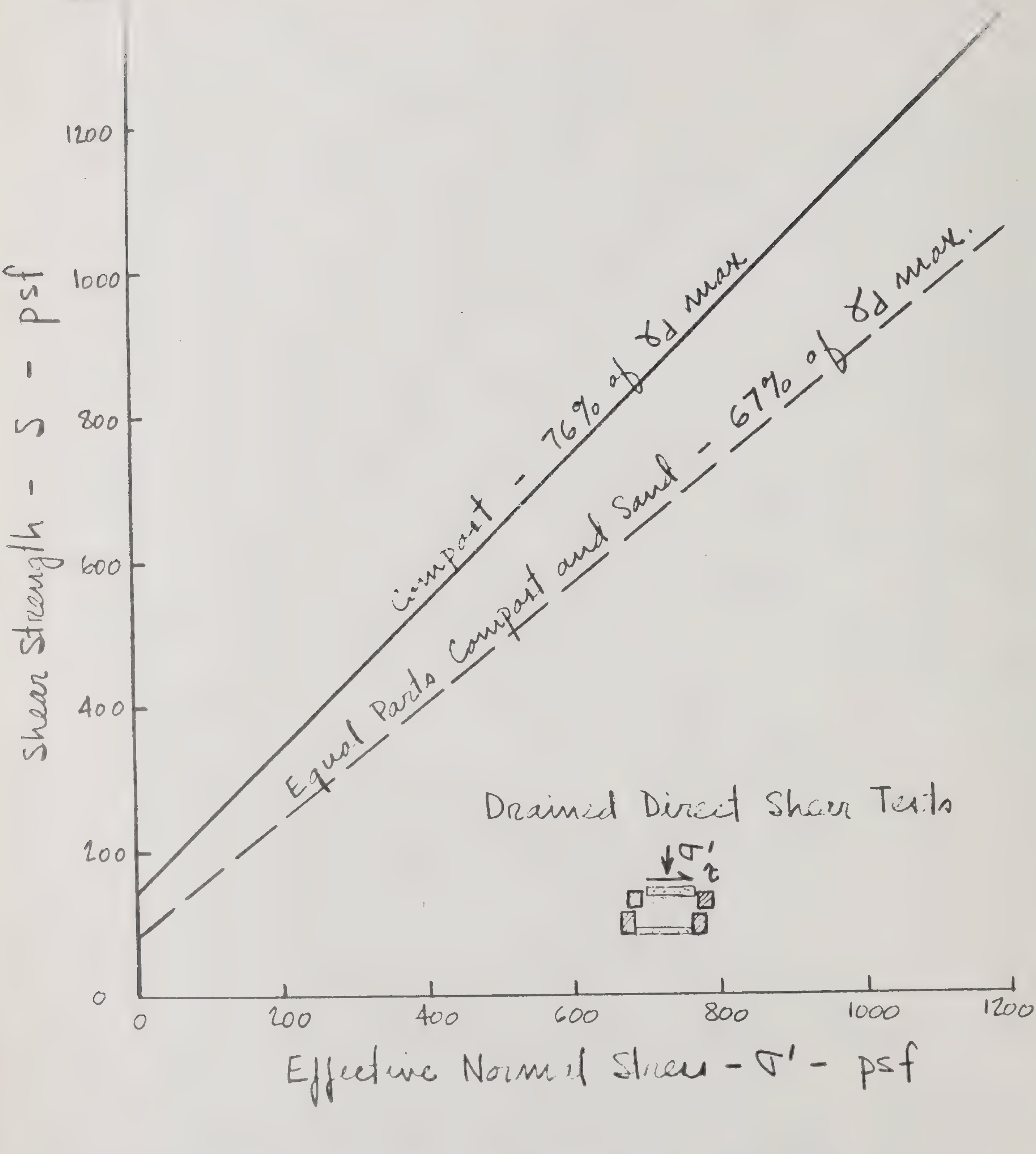
Compression Curves for Compost and Mixture of Compost and Sand.

Figure 7



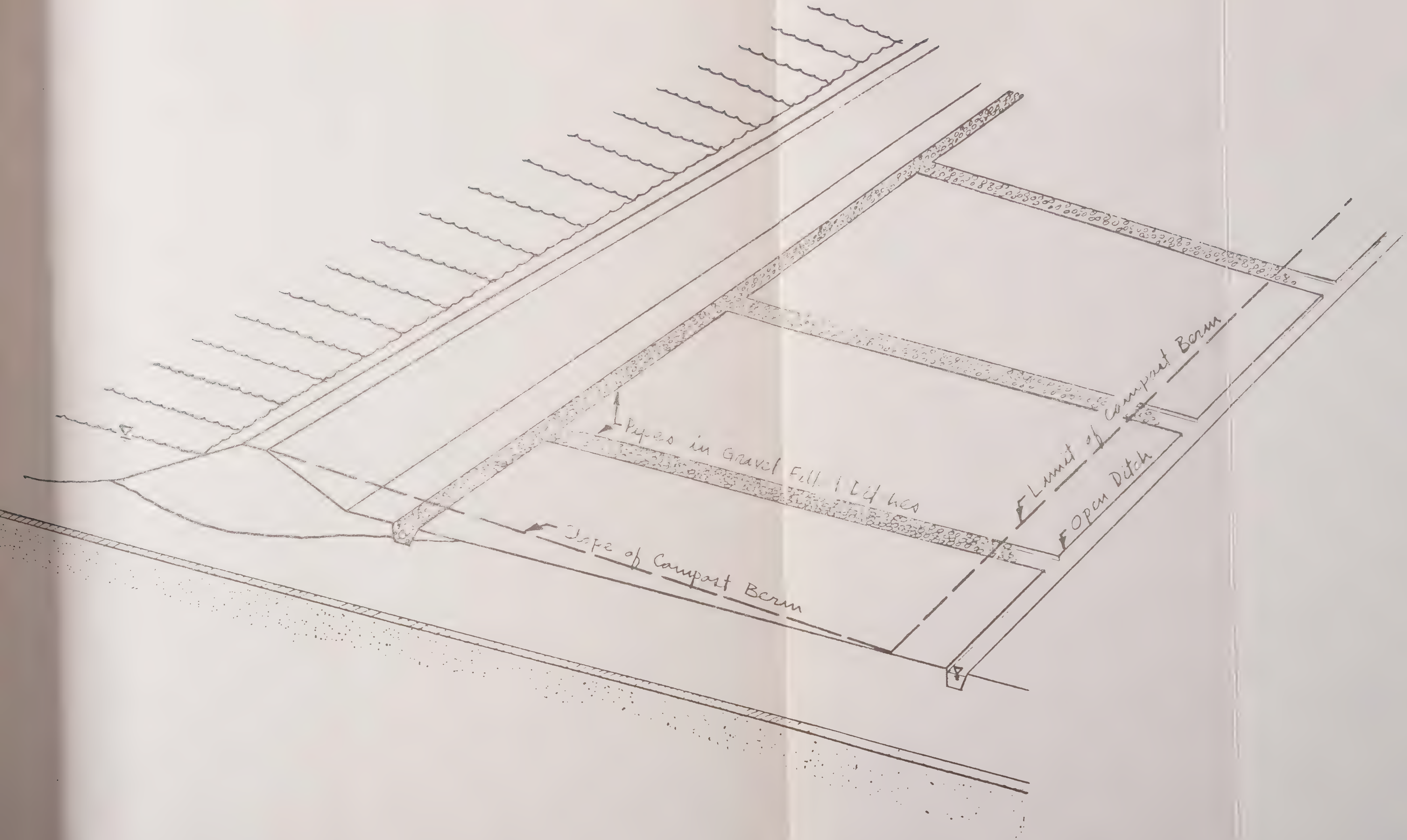
Permeability of Compost and Mixture of Compost and Sand

Figure 8



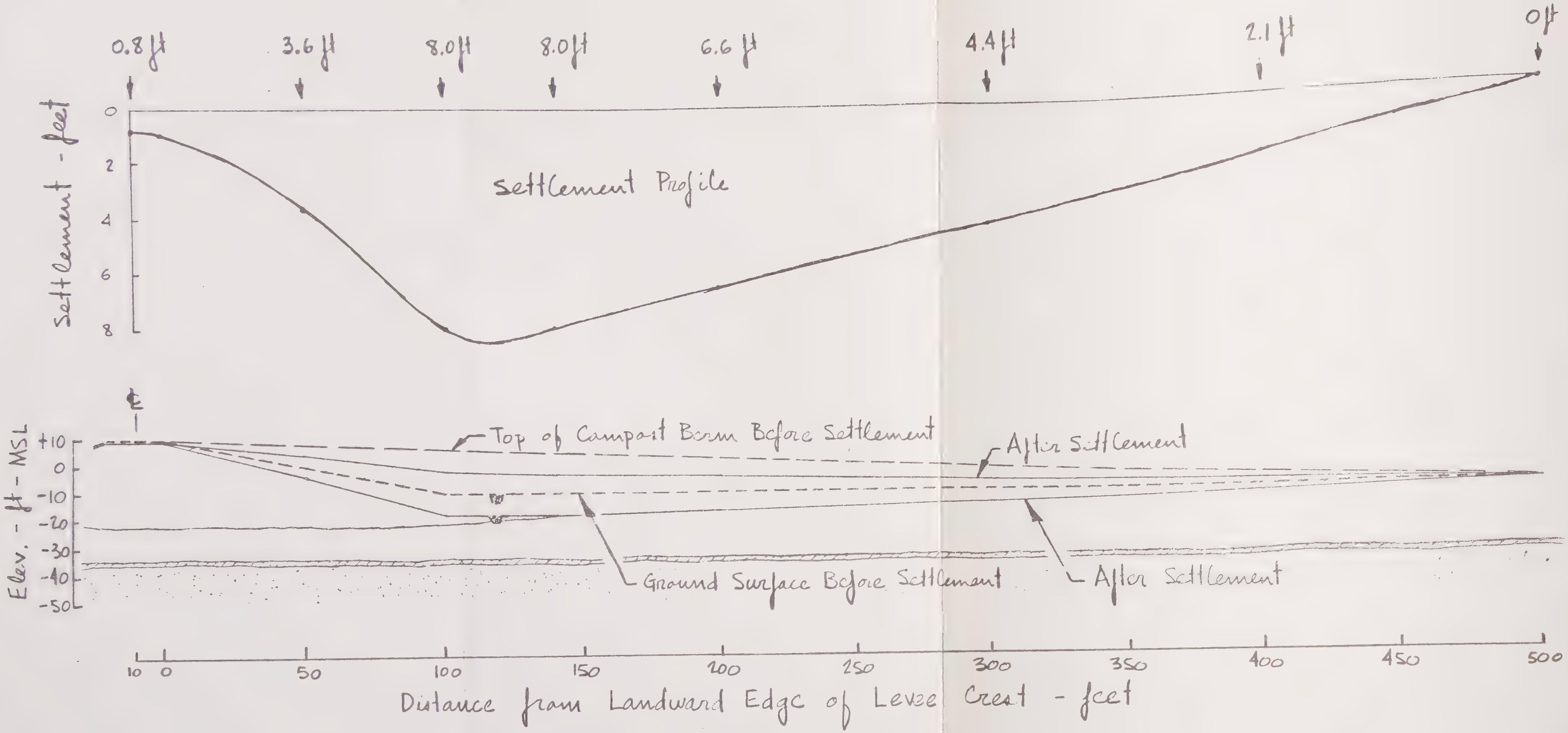
Shear Strength of Compost and Mixture of Compost and Sand

Figure 9



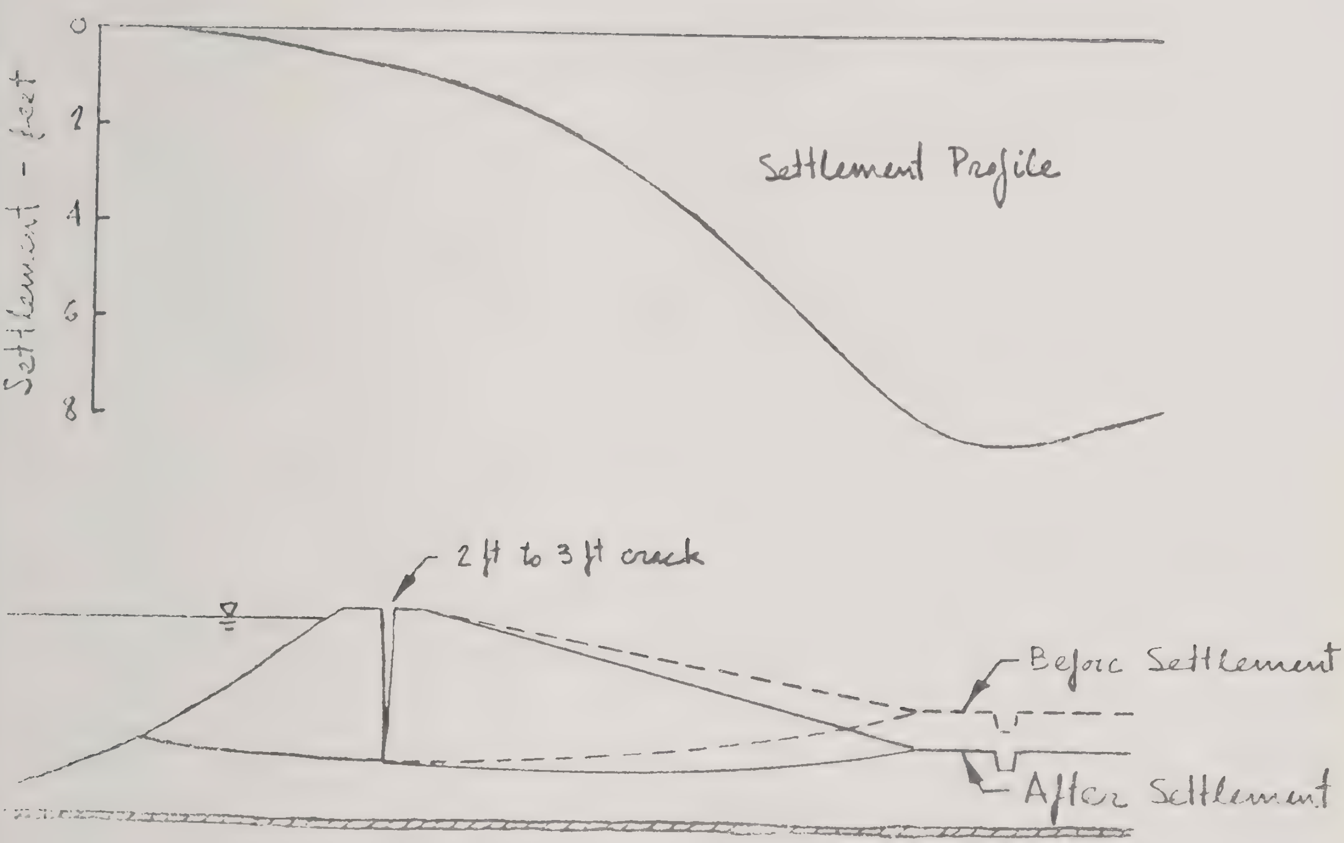
Subdrain System For Compost Berm

Figure 10



Settlement Due To Weight of Compost Berm

Figure 11.



Cracking Due to Nonuniform Settlement

Figure 12

Appendix A

Characteristics of Screened-Compost Material Used as Soil

University of California
Department of Civil Engineering
CE 299 - Individual Research

Presented by: Celso Ugas

for Professor J. M. Duncan

Table of Contents

Synopsis

This paper shows the results obtained from laboratory tests on a new material which is a mixture of shredded municipal refuse and sewage sludge. This material will probably be used as soil in an effort to stabilize the levees in the Delta of the Sacramento and San Joaquin rivers.

Some characteristics such as compaction and compression of this material are presented, as well as values of permeability and drained shear strength for different water contents and dry densities. In addition, some physical properties are described.

Introduction

The Delta, located at the confluence of the Sacramento and San Joaquin rivers, is in the west-central part of the Great Valley of California. It covers an area of about 415,000 acres of land, referred to as Delta Lowlands, lying between the elevations of 5 feet above and 20 feet below sea level. This area is composed of peat, organic sediments, and mineral alluvium. Most of the organic soils have been reclaimed by protection from overflow by man-made levees. An intricate system of natural drainage channels and artificial channels form a large number of islands, or so-called tracts.

The Delta is divided into more than sixty definitely named islands and tracts, each a complete reclamation unit or district with levees, drainage systems and irrigation facilities.

There are approximately 1,100 miles of levees throughout the Delta. Most Delta levees are founded on and constructed of locally available, unconsolidated peats and silts of low density, low shear strength and high moisture content. An exception is in the rim land areas, where sandy silts are encountered, and along the main channels of the Sacramento and San Joaquin rivers, where river sands are available (Department of Water Resources (1963).

Complete levee failures have occurred usually involving from 200 to 1,000 feet of levee. The problem actually faced is the stability of existing levees with economically feasible methods of maintenance or corrective treatment to prevent possible failures of reaches of levee.

"Failures result in flooding of an entire island, often causing the complete loss of valuable crops. Closing the levee break and reclaiming the island by pumping are additional expenses," (U. S. Engineer Office, 1944).

Floods due to levee overtopping are infrequent in the central portion of the Delta.

Actually, the Delta levees are being maintained by various methods, according to the ideas of the local man in charge; in many cases however, the maintenance is not good enough to prevent failures.

Scope

The two major issues in levee design in the Delta are stability and consolidation; for this reason a new material to be used as a stabilizer without increasing the settlement so appreciably has been proposed as a solution. This report shows some of the physical, hydraulic and mechanical properties of this new material, as well as properties of the mixture of this material with sand.

These properties may be useful for analytical analysis and/or as a basis for further research.

Material Tested

The new material is obtained as the product of composting of shredded municipal refuse (30 cubic yards) and sewage sludge (3700 gallons). This mixture received four turnings during two months being afterwards screened through a 3/4" shaker screen (Hart, 1973).

At the end of this process the material is quite brown, light in weight, wet, and friable with a faint soil-like odor; it will be referred to in this report as "screened-compost" or simply "compost".

Additional physical properties of the screened-compost determined in the laboratory are the following:

a) Water content

No change in dry weight or any burning of the material was noted after drying the material in an oven for 24 hours at 140°F or 230°F.

Temperature	Water Content, w (%)*
140°F (60°C)	79.5
230°F (110°C)	85.7

*Average of five values or more determined on the material as it was brought to the laboratory.

b) Unit weight.

The moist unit weight of the screened-compost, in a loose state as it was brought to the laboratory, is:

$$\gamma_m = 18.3 \text{ pcf } (0.294 \text{ gr/cm}^3)$$

c) Grain size distribution.

Several samples of screened-compost were dried in the oven at 230°F and then screened through different size sieves. In Fig. A-1 an average grain size distribution curve is shown, as well as the corresponding curve for the Bay Delta Sand, which was mixed with the screened-compost for some parts of the testing program.

d) Microscopic and macroscopic observations.

The particles passing the No. 4 (4.76 mm) sieve were observed through the microscope, with an enlargement of 450 times the real size. The material showed a predominantly fibrous structure composed by small pieces of: newspaper, plastic, glass, clothes, aluminum foil, plastic foil, leaves, straw, and soil. The maximum size of particle was 3/8" (9.51 mm), corresponding to pieces of newspaper mainly. The material passing the No. 100 (0.149 mm) sieve is dust-like.

Description of Investigation

In order to determine some characteristics of the screened-compost material, and a mixture of screened-compost with sand in the proportion 1:1 by weight

(equivalent to 4:1, compost:sand, by volume), the following set of tests was carried out in the soil laboratory:

1 - Compaction
2 - Compression
3 - Permeability
4 - Direct Shear Strength
5 - Filter Behavior

Material Preparation

All the tests mentioned above were performed on the compost material as it was brought to the laboratory, i.e., without additional screening. The compost was first ovendried at 230°F and then a certain amount of water required to achieve the desired water content was added at the same time the material was turned in a mechanical mixer. In the case of the compost-sand mixtures, the sand was added after the water.

Sample Preparation

Except in the compaction test where no particles were removed, particles greater than about 5 mm, estimated by eye, were removed in preparing the test specimens.

In the following pages a test description including sample preparation has been indicated for each particular test performed.

Test Description and Results

1. Compaction.

   The standard AASHO test was performed on both materials: compost and compost-sand mixed 1:1 by weight. The procedure was as usual, so the material was placed in a 4" diameter mold and compacted in three layers with 25 blows on each applied with a hammer of 5.5 lb. (2.45 kg) and 12" (30.5 cm) free-fall.

   The results are summarized in Fig. A-2. Both curves have shapes typical of clay soils.

   The values of optimum water content and maximum dry density obtained are:

Material	w_{opt} %	$\gamma_{d\ max}$, pcf (gr/cm^3)
Screened-compost	75	39.0 (0.625)
Compost and sand (Mixture 1:1 by weight)	50	57.0 (0.913)

On the basis of these results a program for material testing conditions was established involving samples prepared at densities of 90% γ_d max and 75% γ_d max and water contents of w_{opt} and $w_{opt}/2$. The main purpose of this program was to determine how the properties of the material are affected when changes in water content and/or dry density occur. These testing conditions are shown in Fig. A-2.

2. Compression.

Tests were carried out on non-saturated samples with characteristics as shown in Fig. A-2. In order to get the appropriate density, the material was placed into the mold in three layers and each of these were compacted under pressure applied through the Universal compression machine. However, only hand-applied pressure was required for the compost-sand material to achieve densities equal to or less than 75% γ_d max.

Samples were placed into rings of 4" (10.16 cm) diameter and 1" (2.54 cm) high. The loads were applied in increments, being doubled in every increment, starting from 5.5 lb. (2.5 kg) up to 88.3 lb. (40 kg), i.e., from 0.44 psi (0.031 kg/cm^2) up to 7.03 psi (0.495 kg/cm^2). This range of pressures allows consideration of embankments up to 20 feet high.

During preliminary tests the load was left for two hours (see Figs. A-3, A-4), but it was noticed that most of the deformation occurred during the first minute; therefore it was concluded that leaving every load increment for ten minutes might affect the results by less than 3%. In consequence all subsequent tests were performed with load increments every ten minutes.

Every test was duplicated in order to get average values to draw the compression curves which are shown in Figs. A-5 through A-8. All these curves were plotted together in Fig. A-9, where it may be noticed that

variations in initial water content (w_i) do not yield a considerable change in the amount of compression (ε). It may also be observed that for the compost material, an increment of 5 pcf in dry density may yield a maximum of 6% less in compression at pressure of 7 psi.

In Fig. A-9 it is also observed that for the high density range the amount of compression is about 3% less for the compost and sand material than for the compost at 7 psi of pressure. For the low density the inverse is true and the difference is only 1.5%. Therefore there is no significant difference in the amount of compression yielded by either of the tested materials, at least under the conditions here established.

The changes in dry unit weight under vertical pressures are shown in Figs. A-10 and A-11. Here again there is no influence of the water content on the variation of dry density due to the fact that γ_d increases with compression but compression is not affected by water content as shown previously.

The variation of dry unit weight with pressure is essentially linear and equal to 0.80 pcf per 1 psi (144 psf). This is true for pressures equal or greater than 1.5 psi and any of the conditions shown in Figs. A-10 and A-11.

3. Permeability.

Falling head permeability tests were carried out for different water contents and three different densities.

Samples were placed in a loose state and then compacted in the specimen holder with a wooden stick.

Values of permeability for different initial water contents are shown as a function of dry density in Fig. A-12a. In this figure it may be seen that different initial water contents and dry densities may change the permeability values for the compost material; it is also observed that for the same density, the lower the initial water content the larger the permeability. For the compost-sand mixture however, different initial water contents yield the same permeability value.

The data in Fig. A-12b shows that for the same percent of maximum dry density, values of permeability are higher for the compost with

w_i = 40% than for the compost-sand material. However, for w_i = 77% the opposite is true, with permeability values of 4.2×10^{-3} and 5.3×10^{-4} cm sec for maximum dry densities of 70% and 85% respectively. This means that permeability values are 4 or 5 times larger for the compost-sand mixture than for compost material with 77% initial water content.

4. Direct Shear Strength.

Drained direct shear tests were performed on samples with characteristics as indicated in Fig. 2; for each density and moisture condition three samples were tested at different normal pressures.

The sample dimensions were: length = width = 2" (5.08 cm), and variable height from 0.85" (2.16 cm) through 0.95" (2.42 cm).

The testing procedure was as follows: the sample container was flooded with water, then the normal pressure was applied so that the specimen was allowed to consolidate for a period of 30 minutes. After that, direct shear was applied to the material at a velocity of about 0.0067 inches/min.

Because there is no peak in the curves of horizontal displacement vs. shear stress (see Figs. A-13 and A-14), the shear strength has been considered in all cases as being the shear stress corresponding to 0.2 inches of horizontal displacement. On this basis, the drained strength envelopes have been drawn in Figs. A-15 and A-16. In these figures it is also shown that changes in water content do not change the drained strength of either of the materials tested, i.e. the amount of water has no influence on strength.

Both materials show high friction angles (45° and 46.5°), as well as reasonably good strength. It is also observed (see Fig. A-17) that for low densities the cohesion decreases appreciably.

From Fig. A-17 it might be concluded that, for the range of pressure shown, there is no significant difference in the shear strengths of the materials tested.

5. Filter Behavior.

In order to determine the effectiveness of the compost material working as a filter to prevent the washing out of silty soil particles through the compost, a kind of permeability test was carried out by placing the material as shown on Fig. A-18 and then allowing water to pass through the sample for three days. No observable amount of silt particles were washed out during these tests.

Conclusions

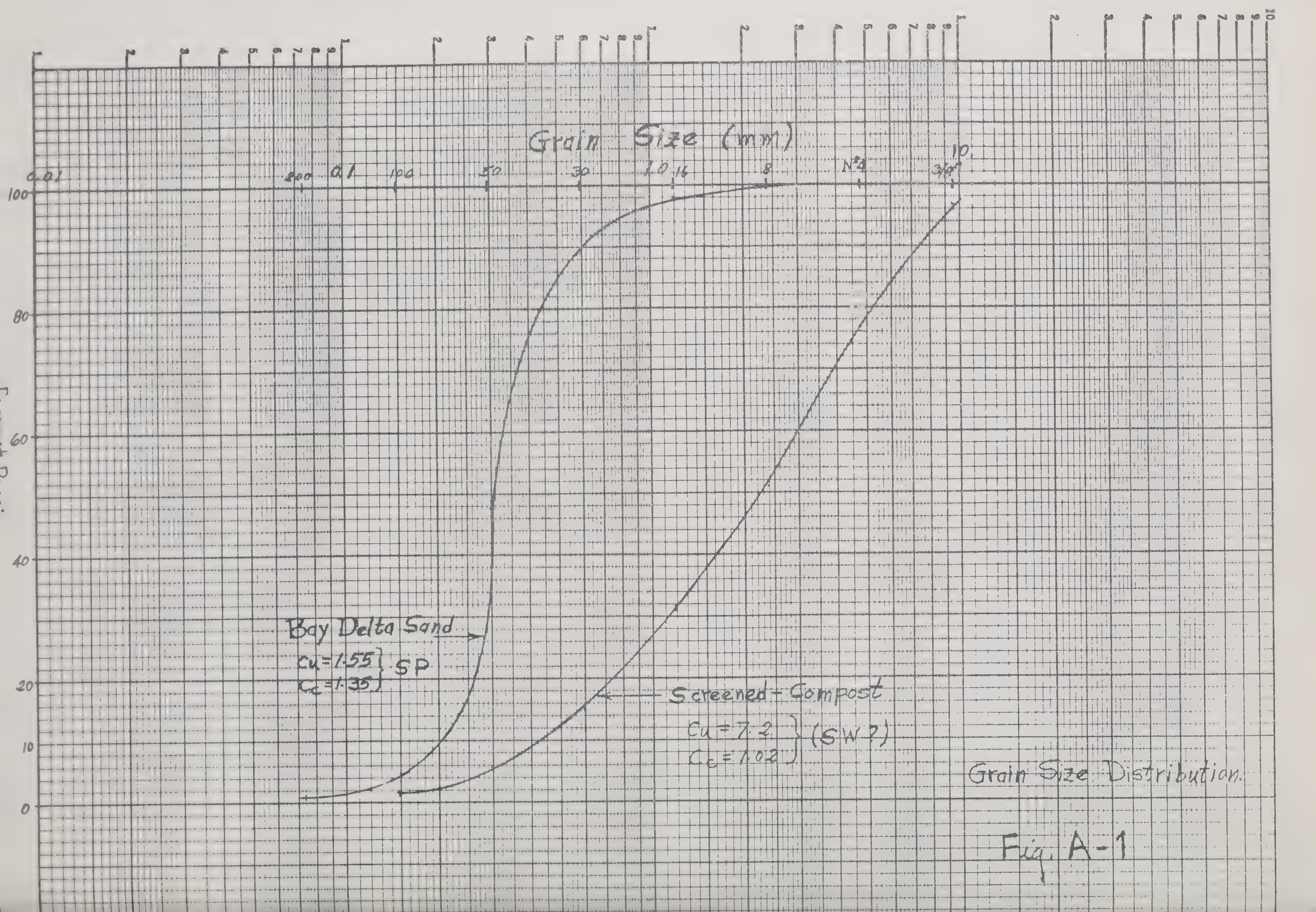
1. The initial water content has no significant effect on either the compression or the drained shear strength characteristics of the compost, but it does influence the permeability values. The lower the water content, the higher the permeability.

2. As a rule of thumb, it might be said that at high pressures (7 psi) an increment of 1 pcf in the dry density may reduce the amount of compression of the compost by about 1%. For the compost-sand mixture, an increment of 1.5 pcf may reduce the compression by about 1%.

3. The compressibility of the compost and compost-sand mixture did not differ significantly; therefore there is no advantage, at least in this respect, to mix the compost with sand. Furthermore, the use of the compost-sand mixture is not advisable because it has higher density than the compost. This would increase the amount of settlement in the peat soil, which is undesirable.

4. The angles of friction for the compost (45°), as well as for the compost-sand (46.5°) are quite satisfactory. In addition, both materials show a cohesion intercept in the order of 1.0 to 3.7 psi at high densities. Again there is no major improvement of the compost strength by adding sand.

5. Mixing sand with the compost does not seem to improve the properties here studied.



Grain Size Distribution.

Fig. A-1

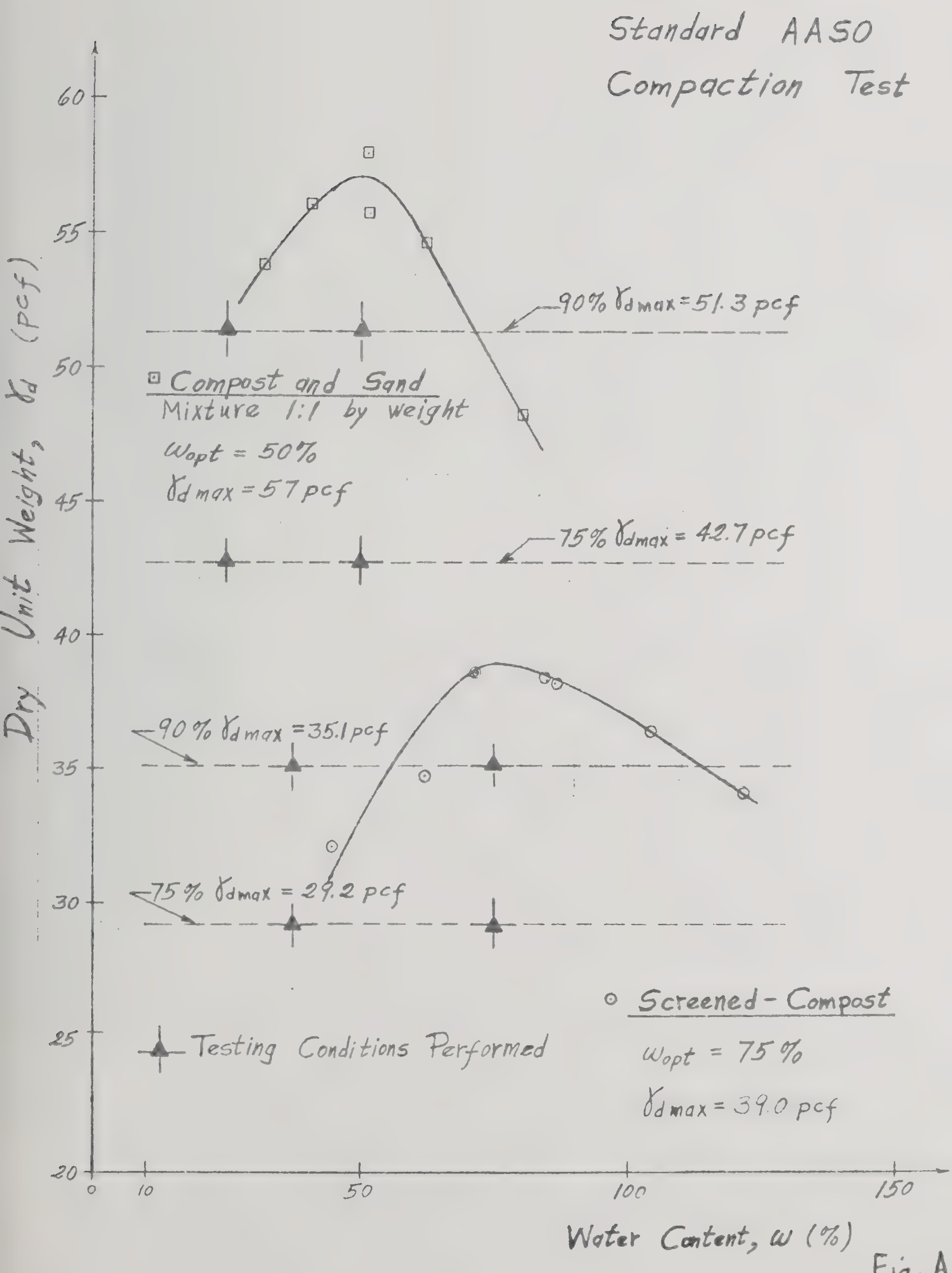
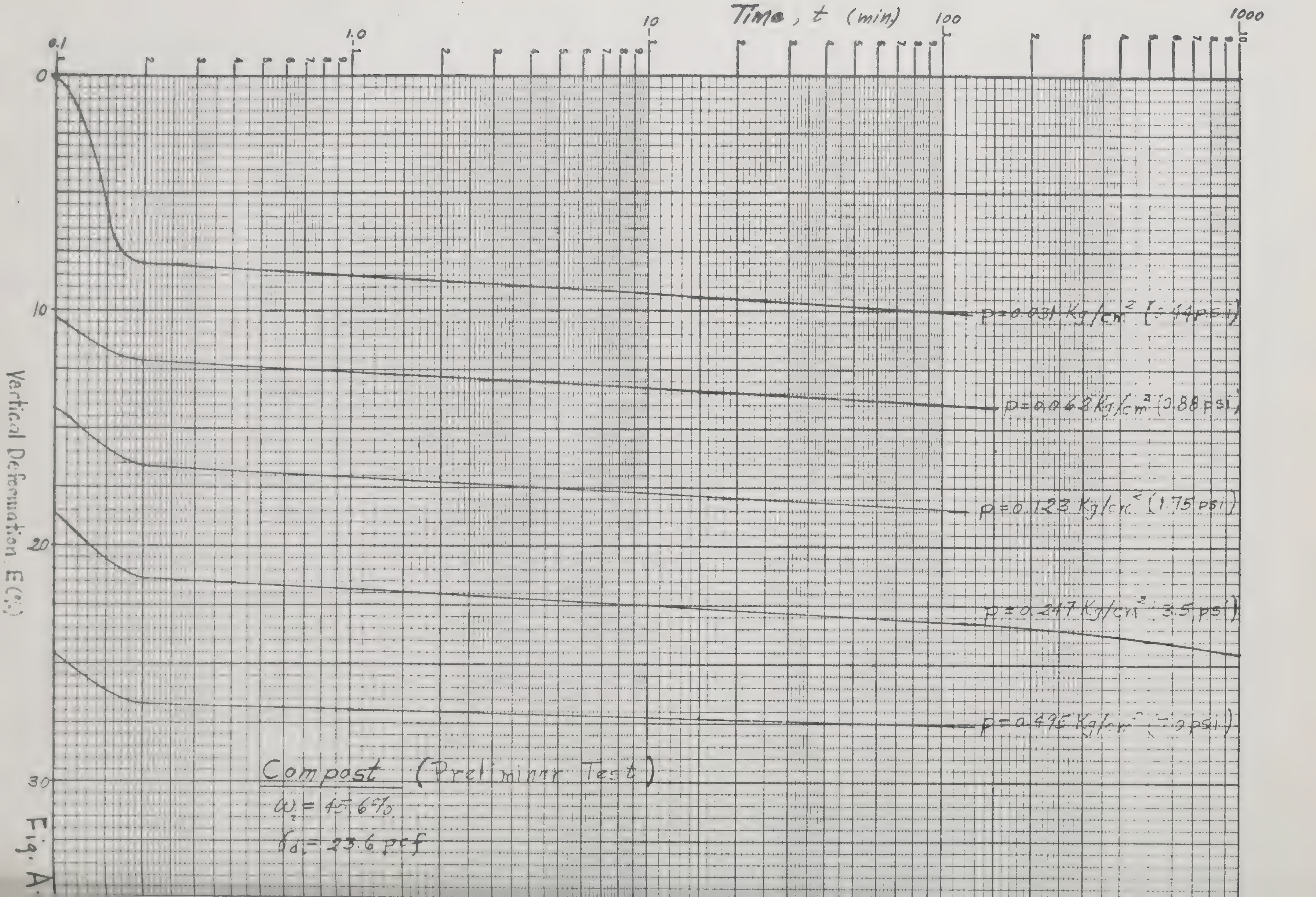
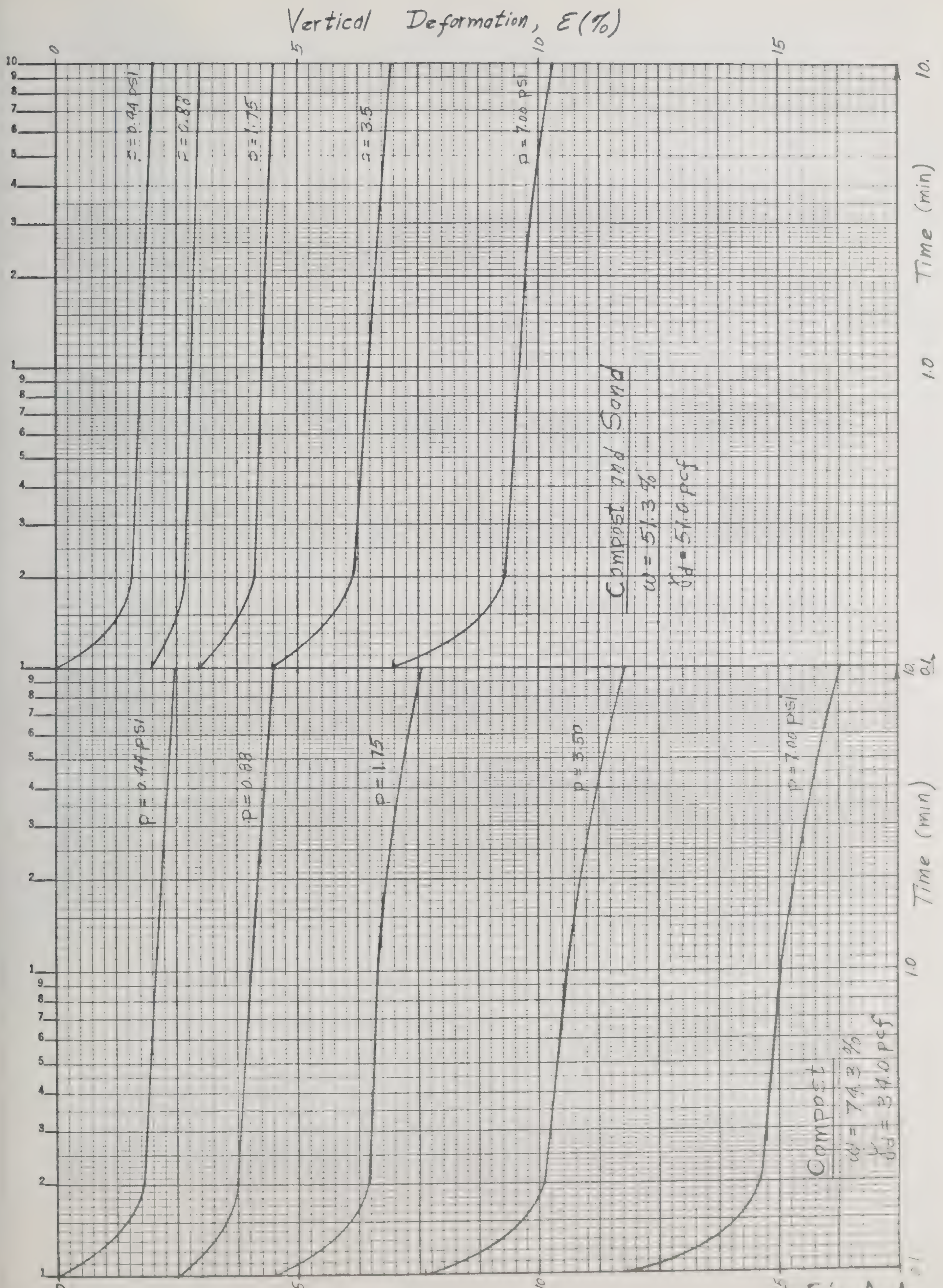

Standard AASO
Compaction Test
90% $\gamma_{d\,max}$ = 51.3 pcf
Compost and Sand
Mixture 1:1 by weight
ω_{opt} = 50%
$\gamma_{d\,max}$ = 57 pcf
75% $\gamma_{d\,max}$ = 42.7 pcf
90% $\gamma_{d\,max}$ = 35.1 pcf
75% $\gamma_{d\,max}$ = 29.2 pcf
Screened-Compost
ω_{opt} = 75%
$\gamma_{d\,max}$ = 39.0 pcf
Testing Conditions Performed
Dry Unit Weight, γ_d (pcf)
Water Content, ω (%)
60
55
50
45
40
35
30
25
20
0
10
50
100
150

Fig. A-2



Time, t (min)
0.1
1.0
10
100
1000
Vertical Deformation E (%)
0
10
20
30
p = 0.031 Kg/cm²
p = 0.062 Kg/cm² (0.88 psi)
p = 0.123 Kg/cm² (1.75 psi)
p = 0.247 Kg/cm² (3.5 psi)
p = 0.495 Kg/cm²
Compost (Preliminary Test)
w_i = 45.6%
γ_d = 23.6 pcf

Fig. A.



Vertical Deformation, E(%)
Time (min)
Time (min)
p = 0.44 psi
p = 0.88
p = 1.75
p = 3.5
p = 7.00 psi
p = 0.44 psi
p = 0.88
p = 1.75
p = 3.50
p = 7.00 psi
Compost and Sand
ω = 51.3 %
γ_d = 51.0 pcf
Compost
ω = 74.3 %
γ_d = 34.0 pcf

Fig. A-4

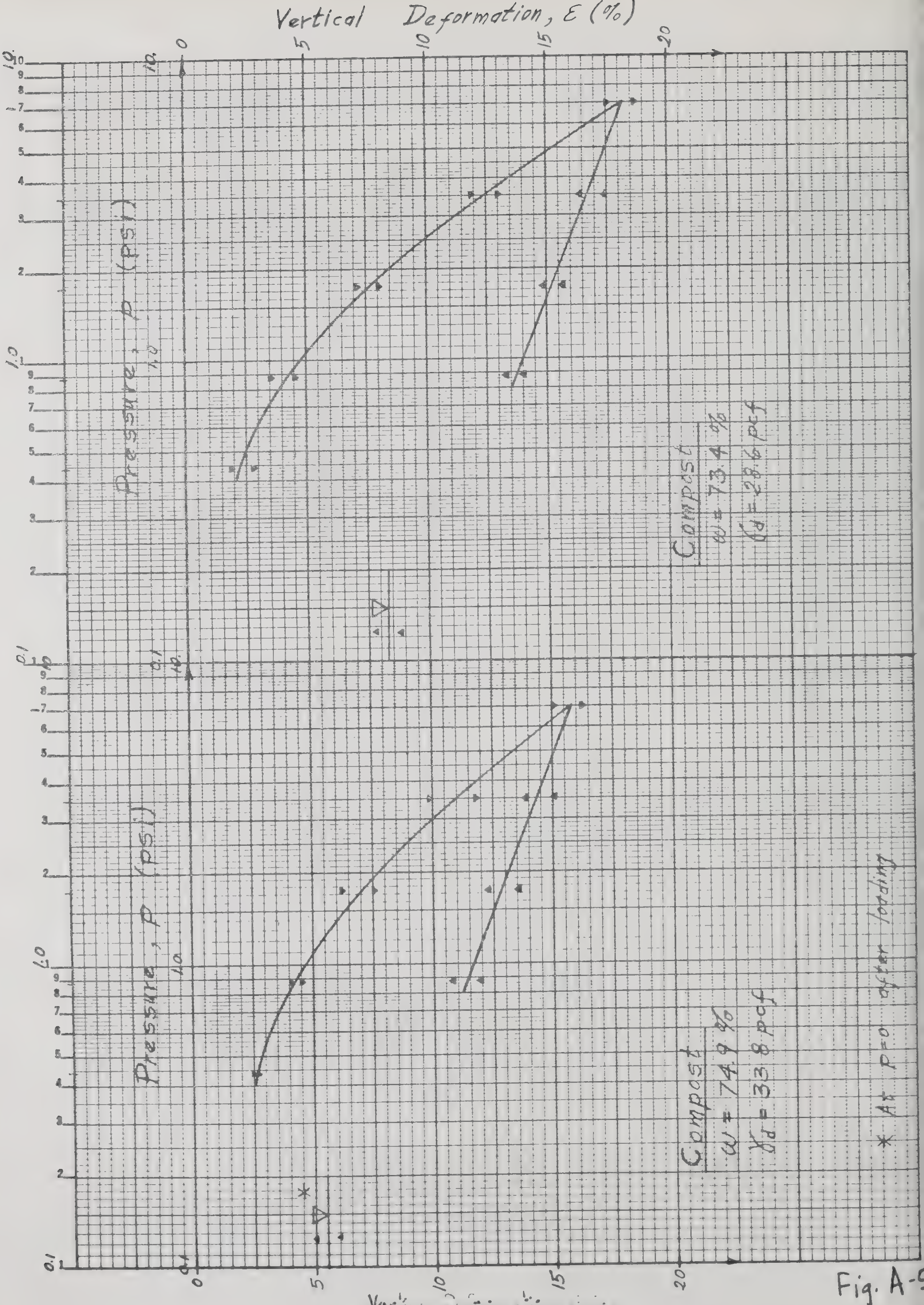
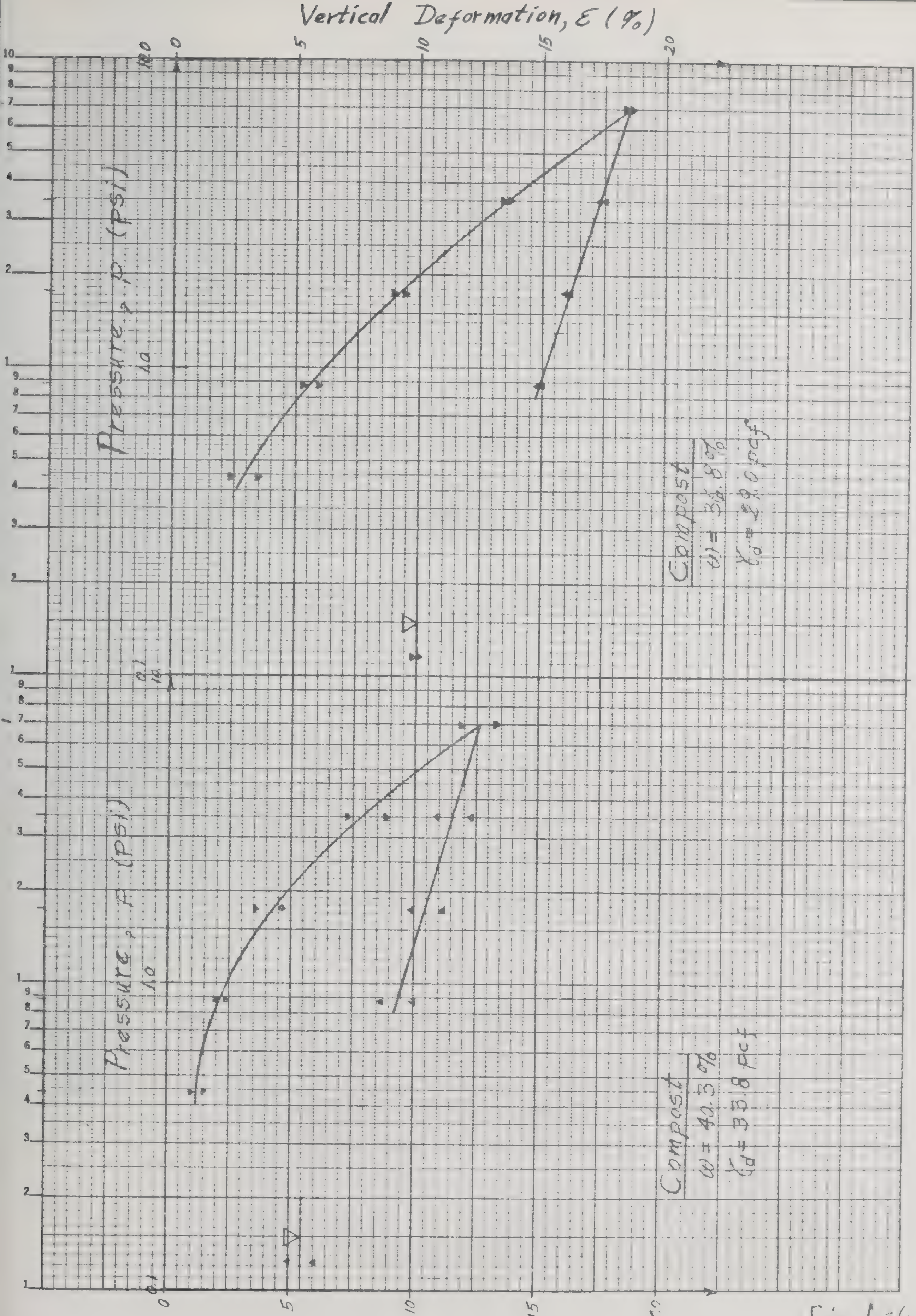
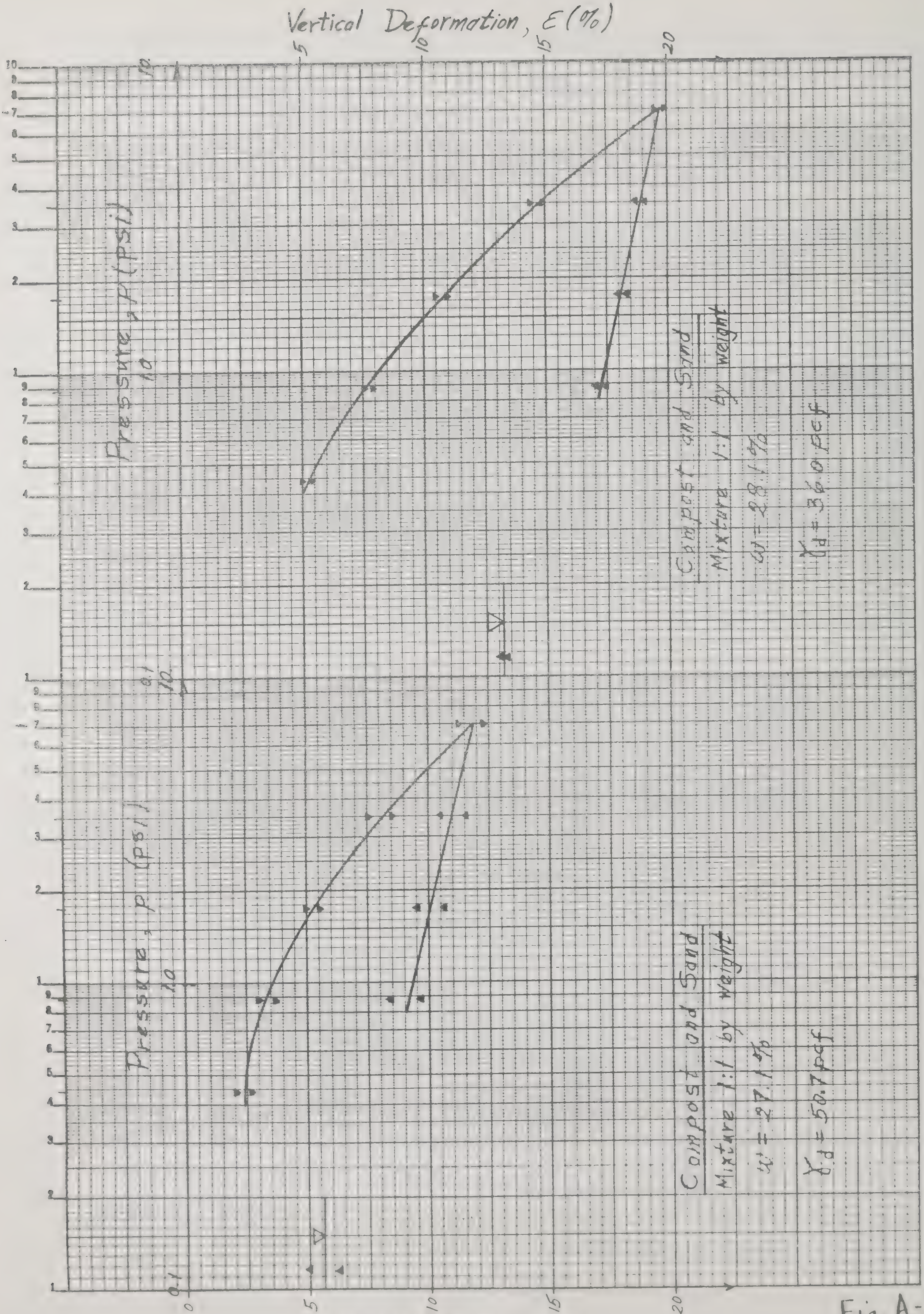

Vertical Deformation, ε (%)
Pressure, p (psi)
Compost
ω = 73.4 %
γd = 28.6 pcf
Pressure, p (psi)
Compost
ω = 74.9 %
γd = 33.8 pcf
* At p=0 after loading

Fig. A-9



Vertical Deformation, ε (%)
Pressure, p (psi)
Compost
Pressure, p (psi)
Compost
ω = 40.5 %
γd = 33.8 pcf

Fig. A-6



Vertical Deformation, ε (%)
Pressure, p (psi)
Compost and Sand
Mixture 1:1 by weight
ω = 28.1 %
γd = 36.0 pcf
Compost and Sand
Mixture 1:1 by weight
ω = 27.1 %
γd = 50.7 pcf

Fig. A-7

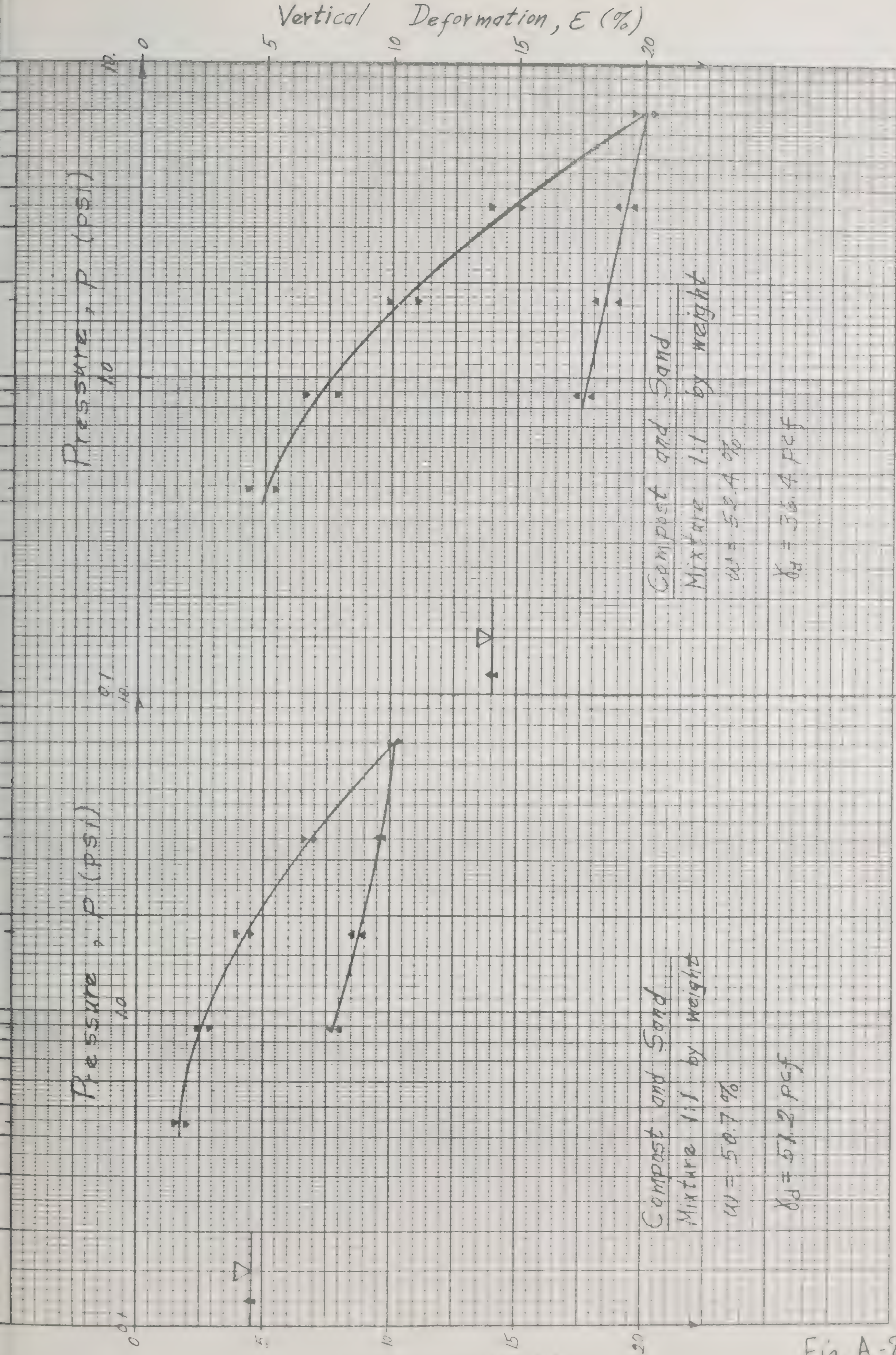

Vertical Deformation, ε (%)
Pressure, p (psi)
Compost and Sand
Mixture 1:1 by weight
Compost and Sand
Mixture 1:1 by weight
w = 50.7 %
γd = 51.2 pcf

Fig. A-8

Vertical Deformation, ε(%)

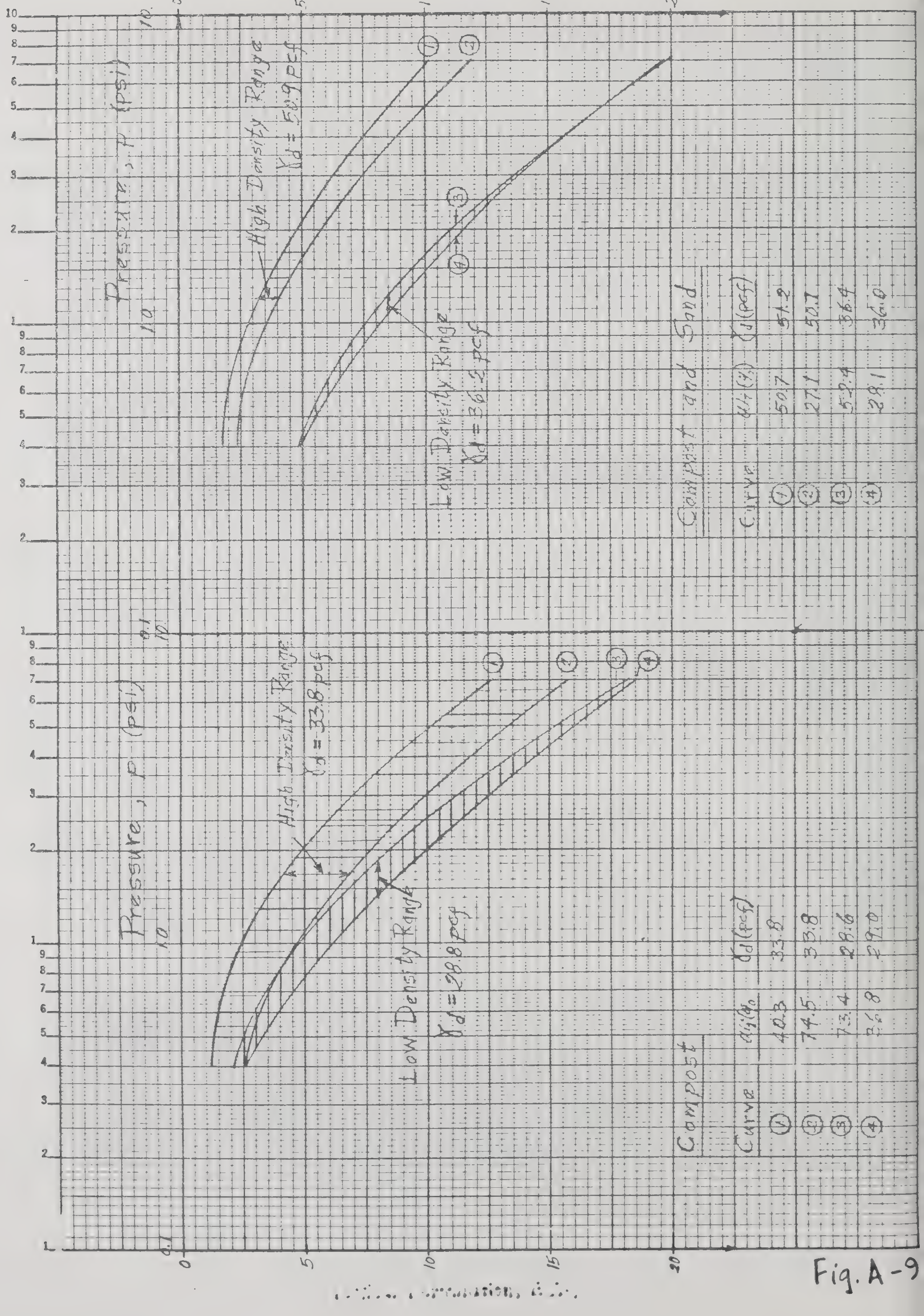


Fig. A-9

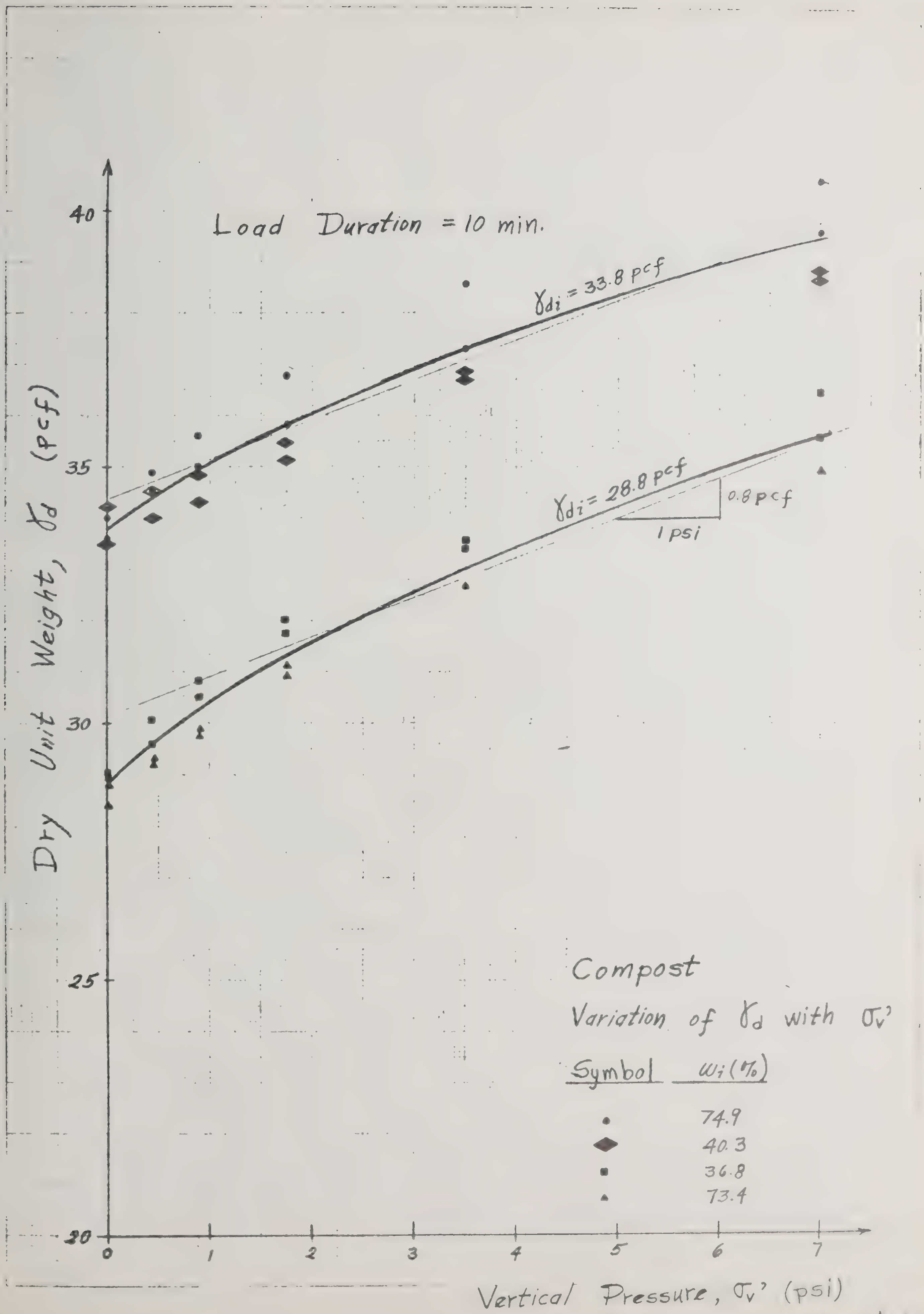

Load Duration = 10 min.
γ_{di} = 33.8 pcf
γ_{di} = 28.8 pcf
0.8 pcf
1 psi
Dry Unit Weight, γ_d (pcf)
40
35
30
25
20
0
1
2
3
4
5
6
7
Vertical Pressure, σ_v' (psi)
Compost
Variation of γ_d with σ_v'
Symbol
w_i (%)
74.9
40.3
36.8
73.4

Fig. A-10

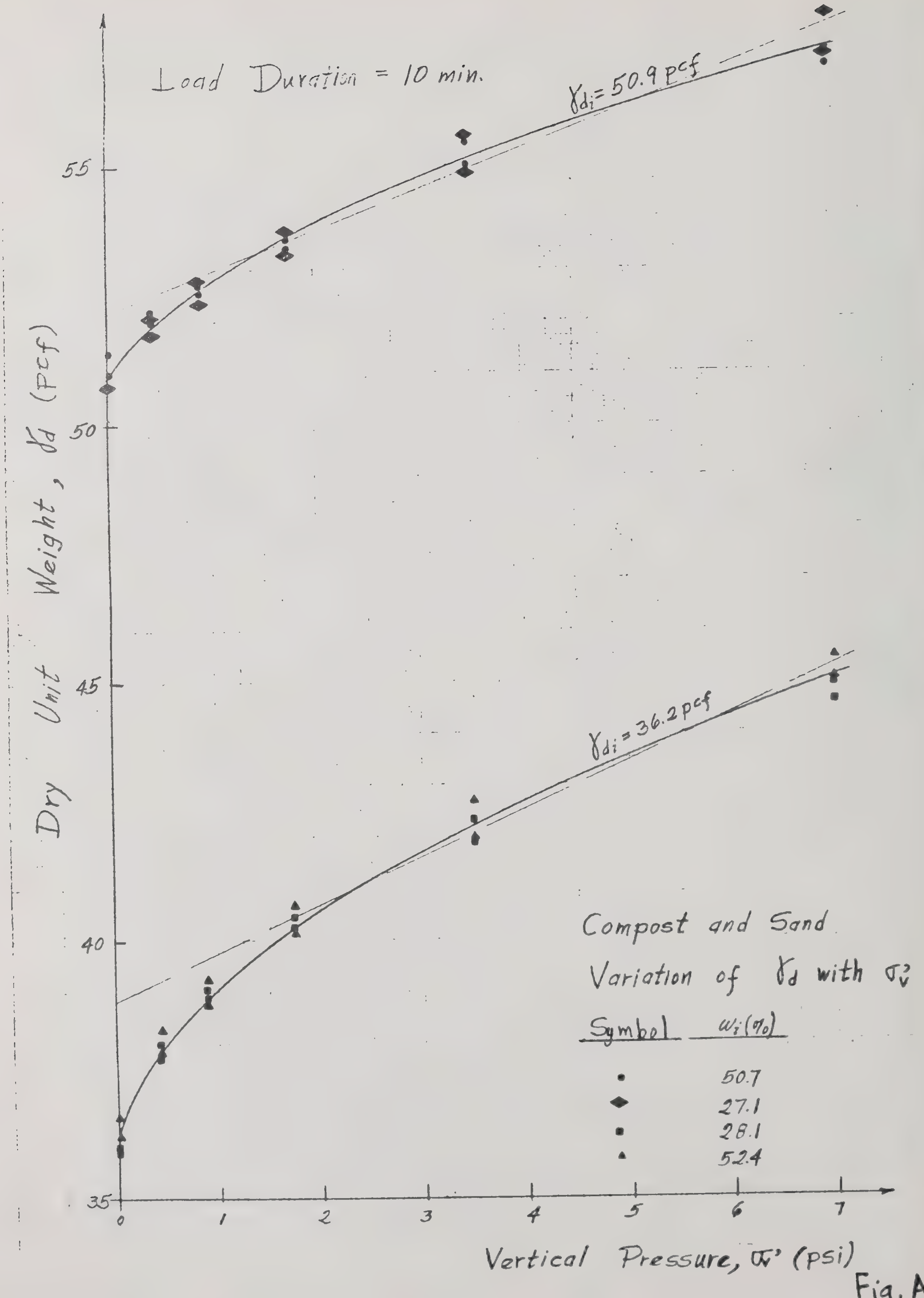
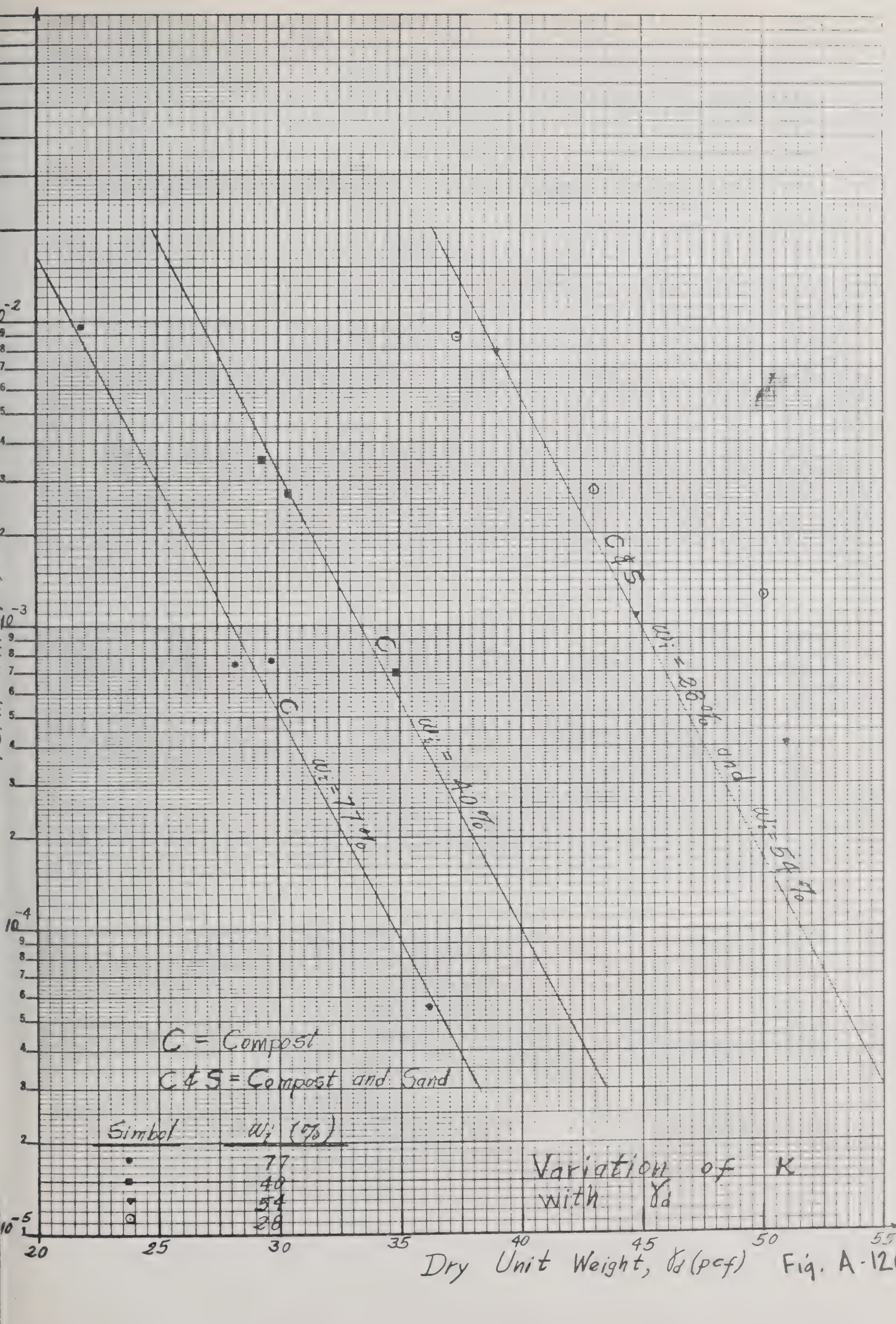

Load Duration = 10 min.
$\gamma_{d_i} = 50.9$ pcf
$\gamma_{d_i} = 36.2$ pcf
Dry Unit Weight, γ_d (pcf)
55
50
45
40
35
0
1
2
3
4
5
6
7
Compost and Sand
Variation of γ_d with σ_v'
Symbol w_i(%)
50.7
27.1
28.1
52.4
Vertical Pressure, σ_v' (psi)

Fig. A-11



C
C
C & S
$w_i = 77\%$
$w_i = 40\%$
$w_i = 26\%$ and $w_i = 54\%$
C = Compost
C & S = Compost and Sand
Simbol
w_i (%)
77
40
54
26
Variation of K with γ_d
Dry Unit Weight, γ_d (pcf)
20
25
30
35
40
45
50
55

Fig. A-12(a)

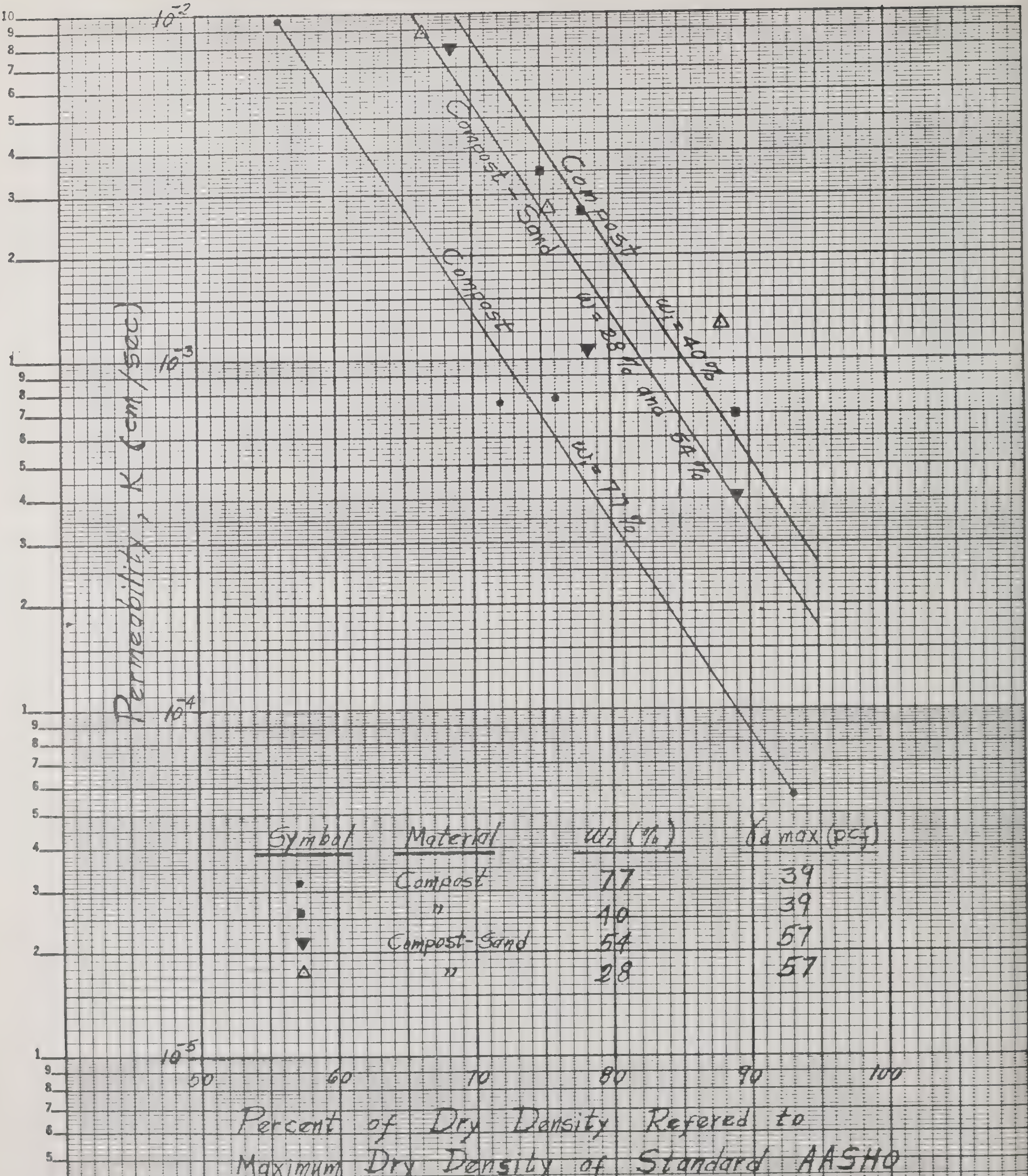


Fig. 12b

Permeability of Compost and Compost-Sand Mixture

Fig. A-12(b)

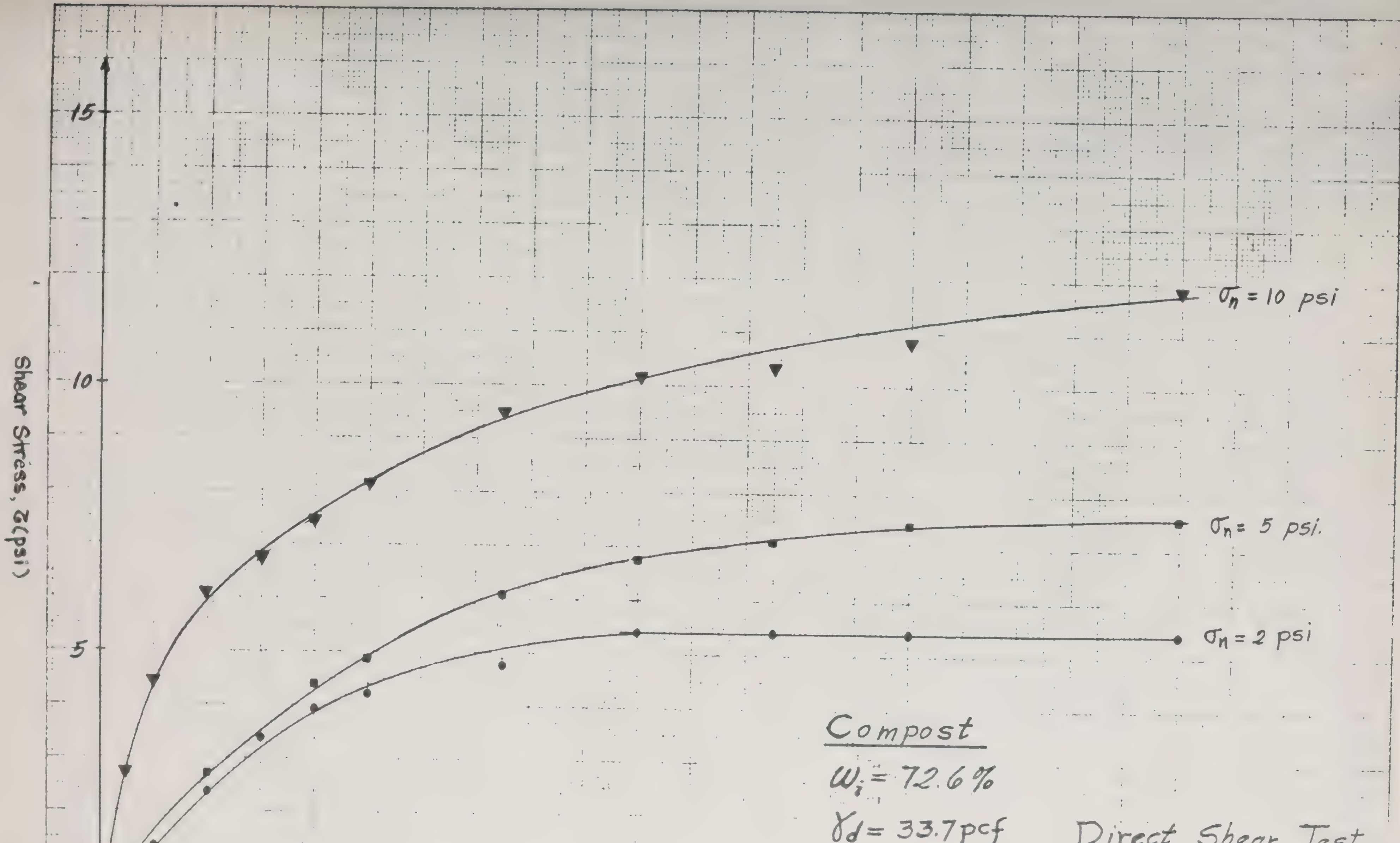
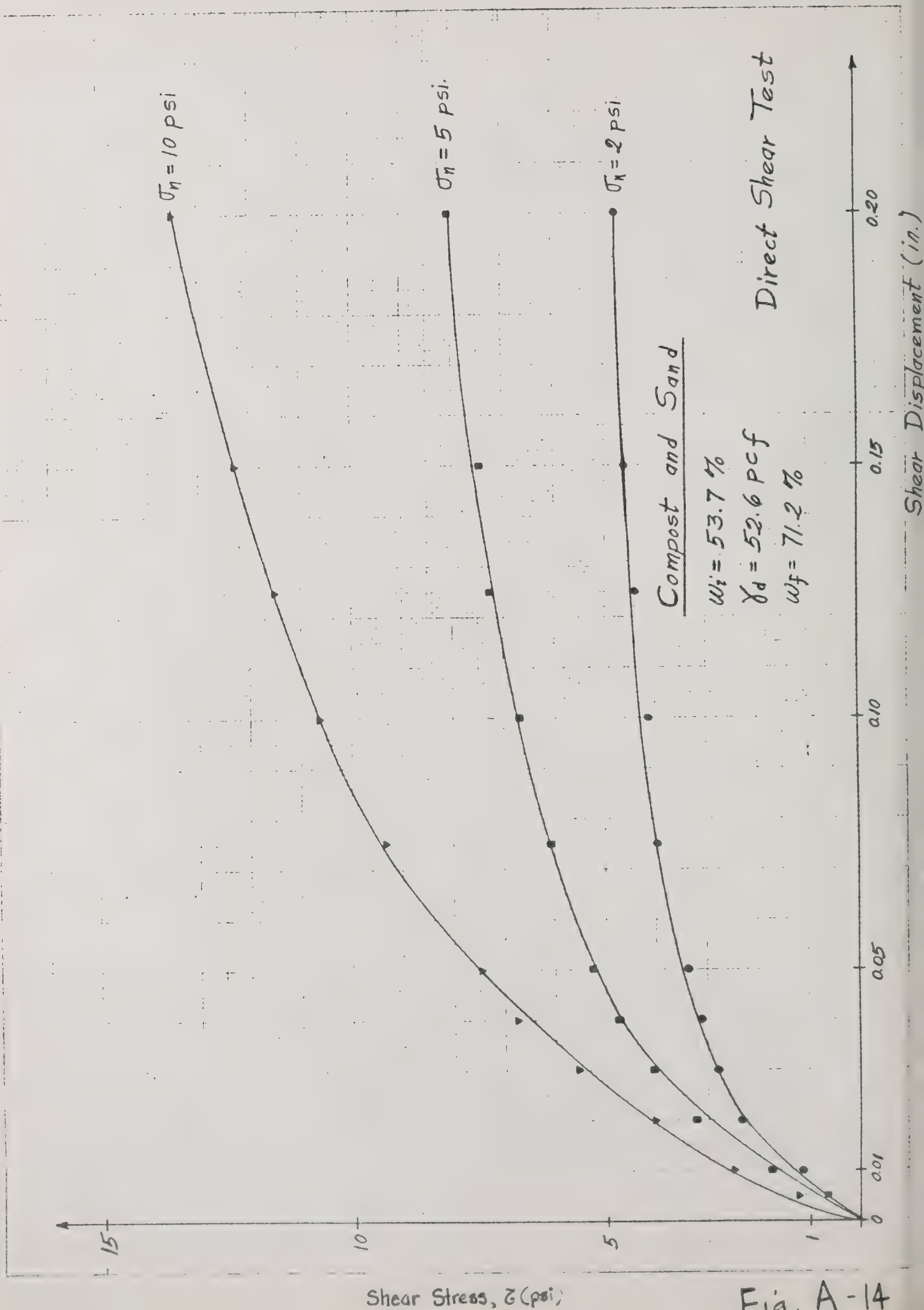

Shear Stress, τ(psi)
$\sigma_n = 10$ psi
$\sigma_n = 5$ psi.
$\sigma_n = 2$ psi
Compost
$\omega_i = 72.6\%$
$\gamma_d = 33.7$ pcf
$\omega_f = 124.5\%$
Direct Shear Test
0
1
5
10
15
0.01
0.05
0.10
0.15
0.20

Fig. A-12



$\sigma_n = 10$ psi
$\sigma_n = 5$ psi.
$\sigma_n = 2$ psi
Compost and Sand
$w_i = 53.7$ %
$\gamma_d = 52.6$ pcf
$w_f = 71.2$ %
Direct Shear Test
0
0.01
0.05
0.10
0.15
0.20
Shear Displacement (in.)
1
5
10
15
Shear Stress, τ (psi)

Fig. A-14

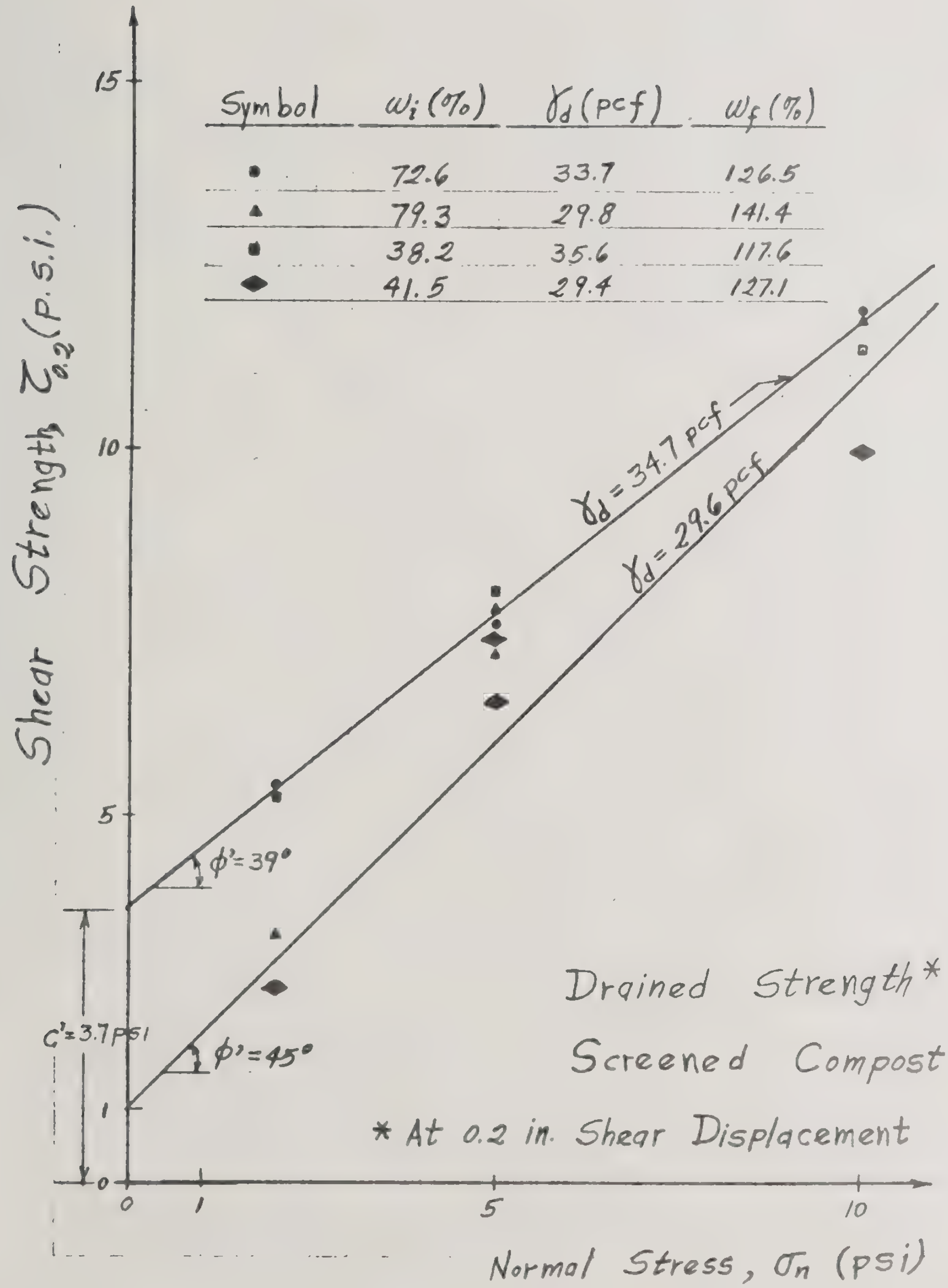

Symbol
ω_i (%)
γ_d (pcf)
ω_f (%)
72.6
33.7
126.5
79.3
29.8
141.4
38.2
35.6
117.6
41.5
29.4
127.1
γ_d = 34.7 pcf
γ_d = 29.6 pcf
ϕ'=39°
ϕ'=45°
C'=3.7 PSI
Shear Strength $\tau_{0.2}$ (p.s.i.)
Normal Stress, σ_n (psi)
Drained Strength*
Screened Compost
* At 0.2 in. Shear Displacement
15
10
5
1
0
0
1
5
10

Fig. A-15

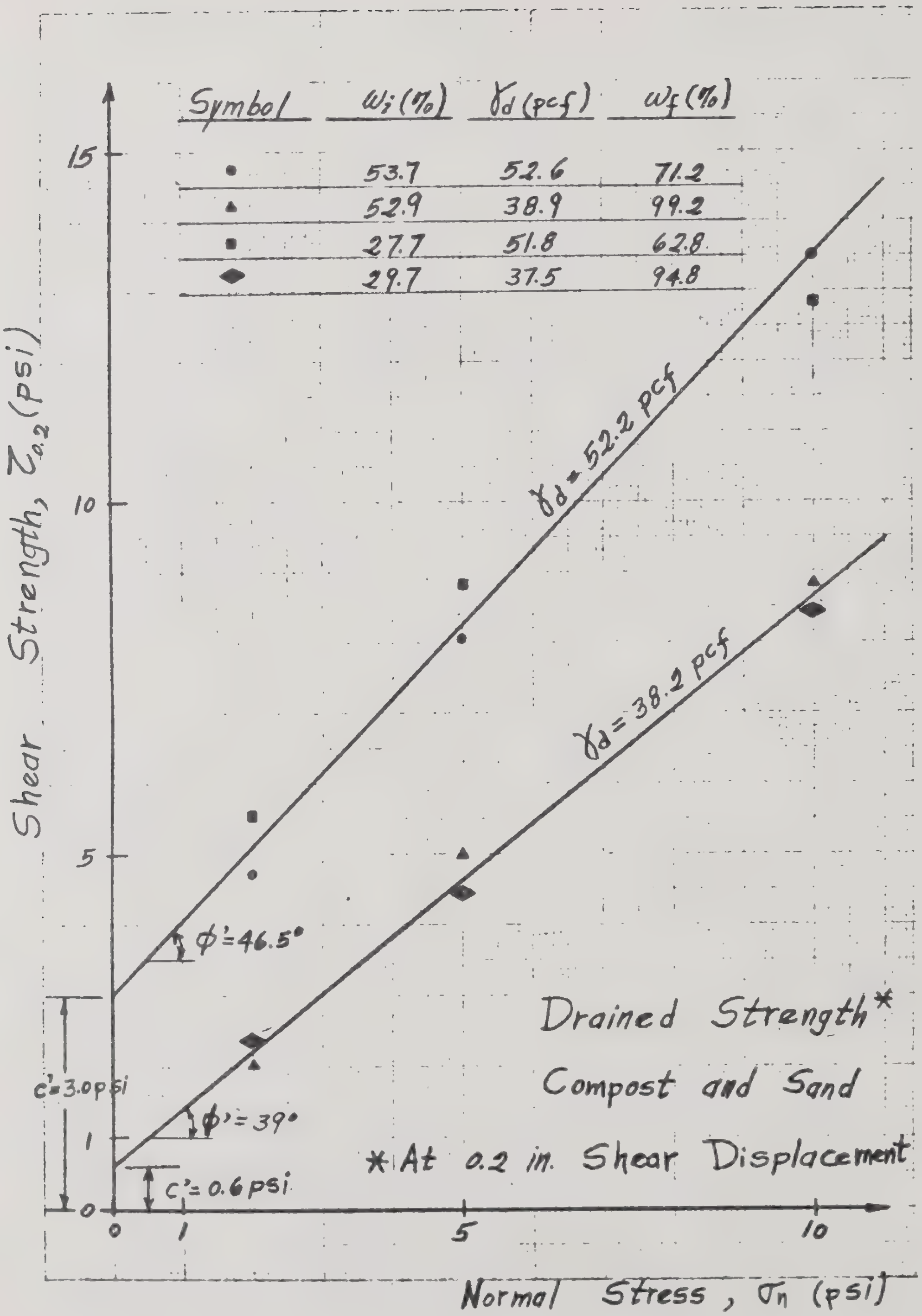
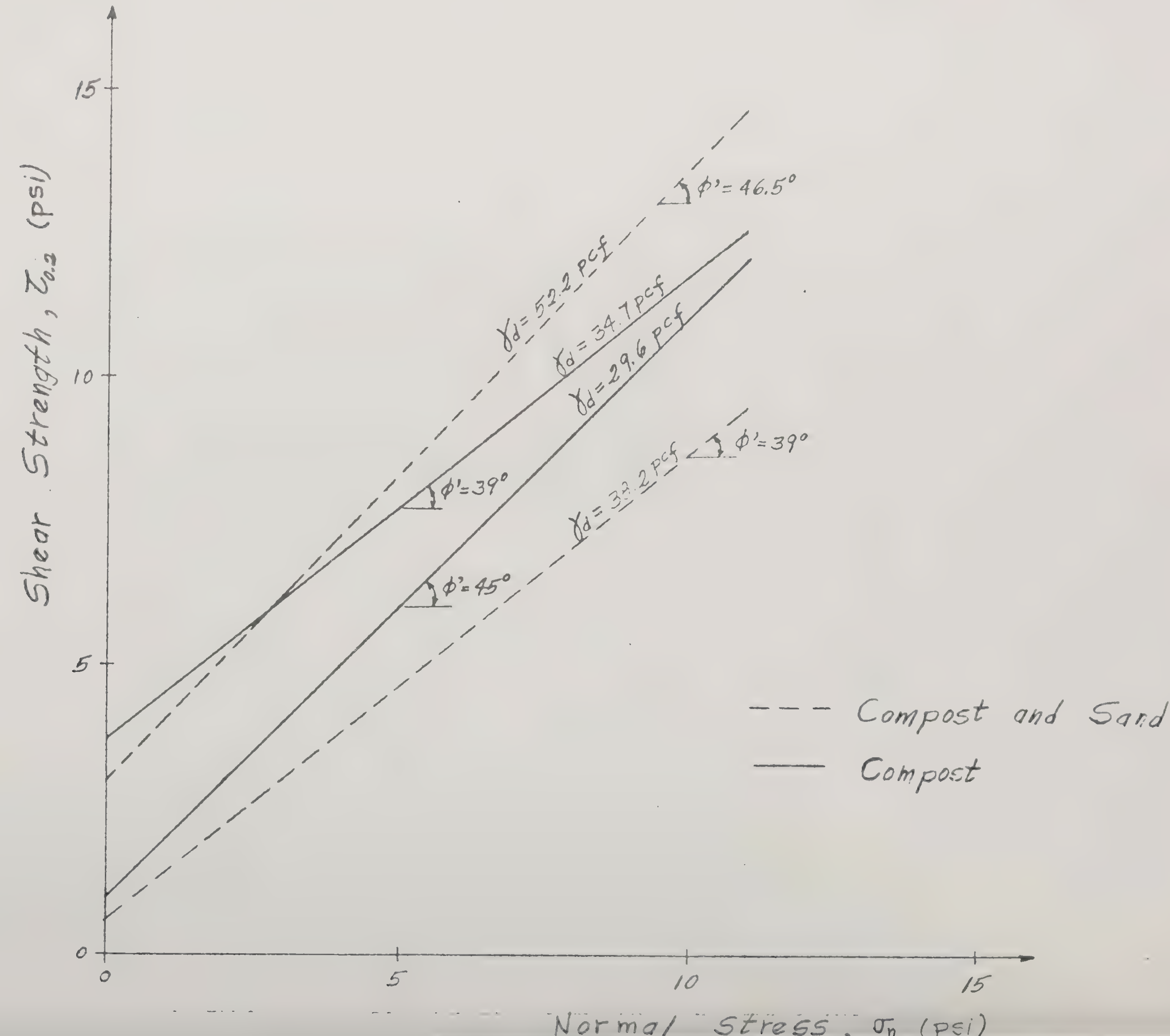
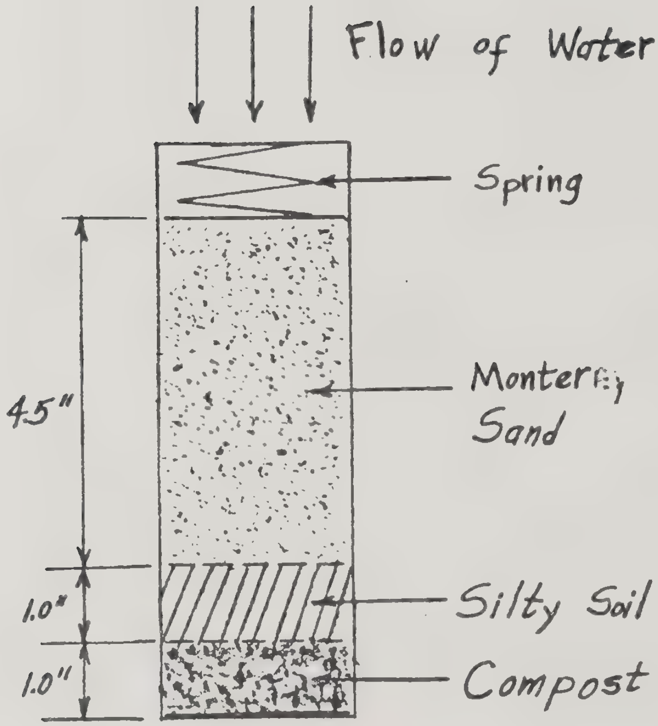

Symbol
ωi (%)
γd (pcf)
ωf (%)
53.7
52.6
71.2
52.9
38.9
99.2
27.7
51.8
62.8
29.7
37.5
94.8
Shear Strength, τ0.2 (psi)
Normal Stress, σn (psi)
γd = 52.2 pcf
γd = 38.2 pcf
φ' = 46.5°
φ' = 39°
c' = 3.0 psi
c' = 0.6 psi
Drained Strength*
Compost and Sand
* At 0.2 in. Shear Displacement
0
1
5
10
15

Fig. A-16


Shear Strength, $\tau_{0.2}$ (psi)
Normal Stress, σ_n (psi)
0
5
10
15
γ_d = 52.2 pcf
ϕ' = 46.5°
γ_d = 34.7 pcf
ϕ' = 39°
γ_d = 29.6 pcf
ϕ' = 45°
γ_d = 33.2 pcf
ϕ' = 39°
Compost and Sand
Compost



Filter Behavior Test

Fig. A-18

Appendix B

Tests on Older Compost

After the tests and analyses described in the report and in Appendix A had been completed, an older compost of municipal waste, prepared at the Metro Composting Plant in Houston, Texas, became available for testing. The material was prepared from shredded municipal waste in a 6-day composting process and had aged outdoors for 1-1/2 years since its production. It is dark brown with soft, fluffy particles which appeared to be more thoroughly decomposed than the younger compost tested previously.

Compaction tests, permeability tests, compression tests, and strength tests were performed on the material, and the results were compared to the results of tests on the younger compost. The results of these tests are shown in Figs. B-1 through B-4.

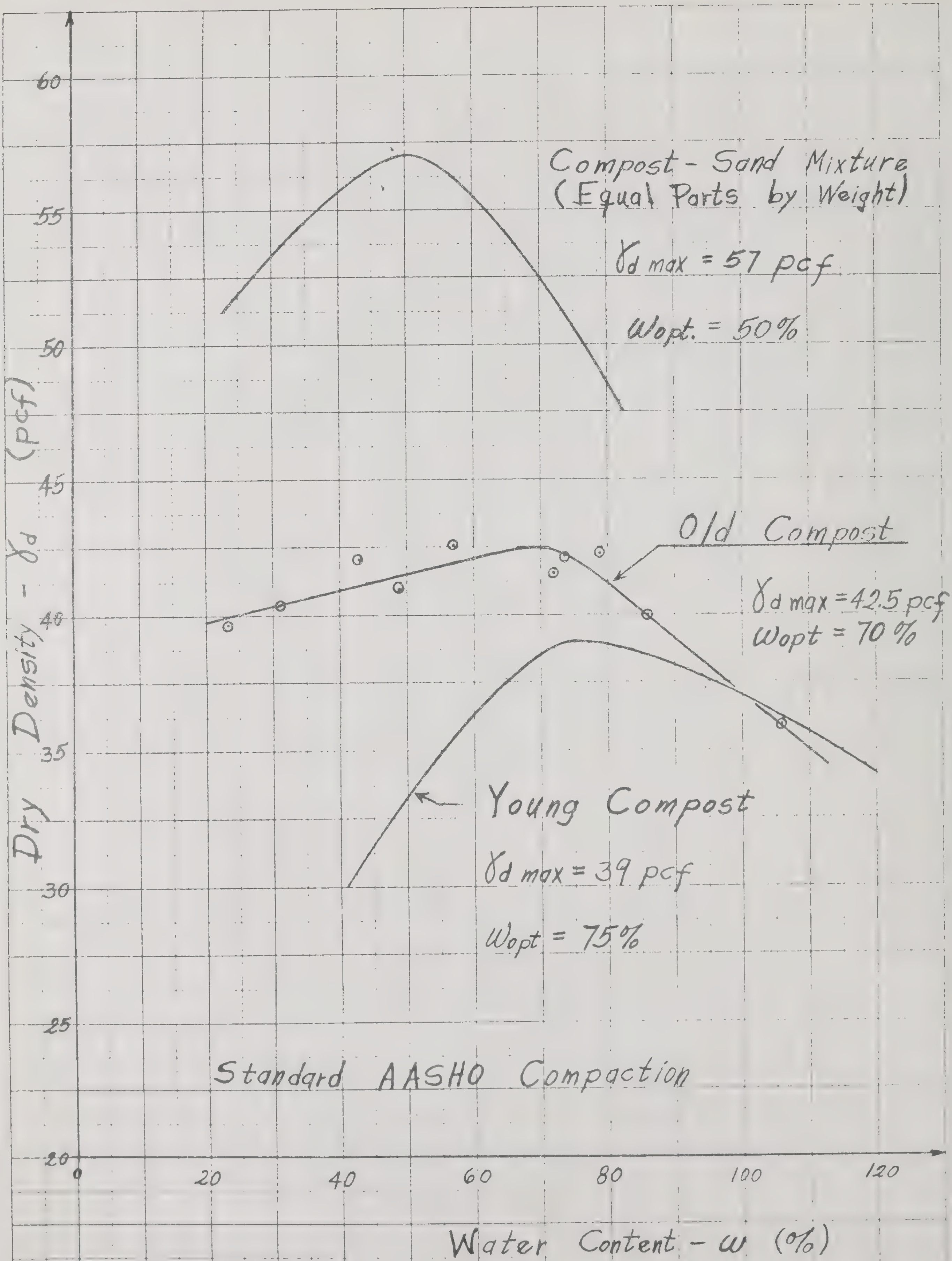
The compaction test results in Fig. B-1 show that the old compost has a slightly higher maximum dry density than the young compost, 42.5 lb/ft^3 as compared to 39 lb/ft^3. The optimum water content of the older material is slightly lower, however, 70% as compared to 75%. As a result, the corresponding moist density of the old compost is not much different from that of the young compost. At 85% of the maximum dry density and a water content 25% above optimum, the moist density of the old compost would be 70 lb/ft^3 as compared to 66 lb/ft^3 for the young compost. This 6% greater density would correspond to 6% greater settlement under an equal volume of fill. This difference is probably less than the accuracy of the data and analyses in this report and therefore appears not to be significant.

The permeability test results in Fig. B-2 indicate that the old and the young composts have about the same values of permeability.

The compression test data in Fig. B-3 shows that the compressibility of the specimen of old compost which was tested was less than that of the specimens of young compost. The old compost was compacted to a higher percentage of maximum dry density, however, and this difference in density appears to be the main reason for the difference in compressibility. At equal percentages of the maximum dry densities, the compressibilities of the old and young composts would probably be very nearly the same.

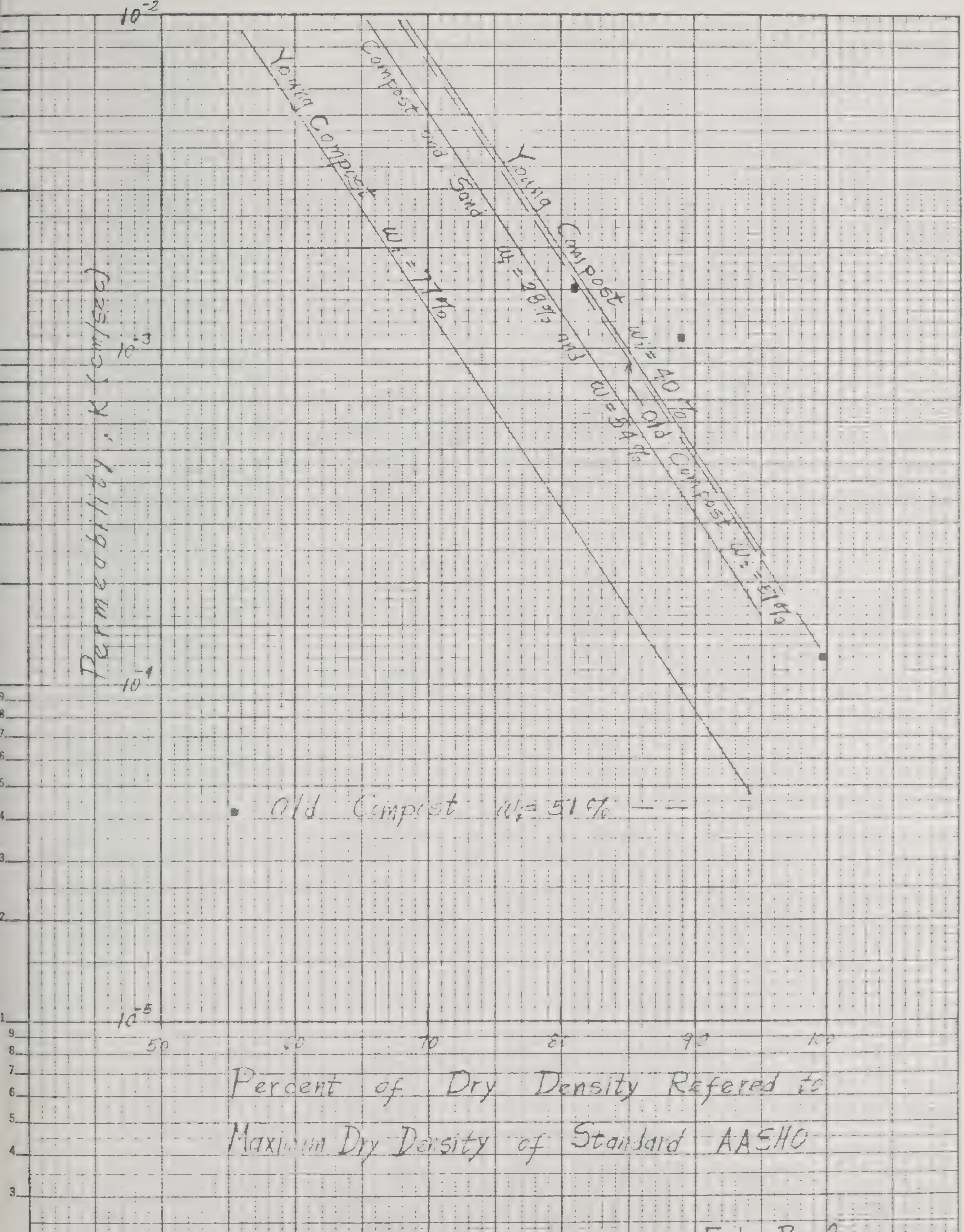
The strength test results are shown in Fig. B-4. It can be seen that the older compost is stronger than the young compost, but the difference is probably the result of higher specimen densities. It appears that specimens of the old compost would have about the same strength as the young compost at equal percentages of maximum density.

On the basis of these tests it can be concluded that the densities, permeabilities, compressibilities, and strengths of the two compost materials are very nearly the same. The analyses and conclusions of the main report would therefore appear to apply to the older material as well as the younger.



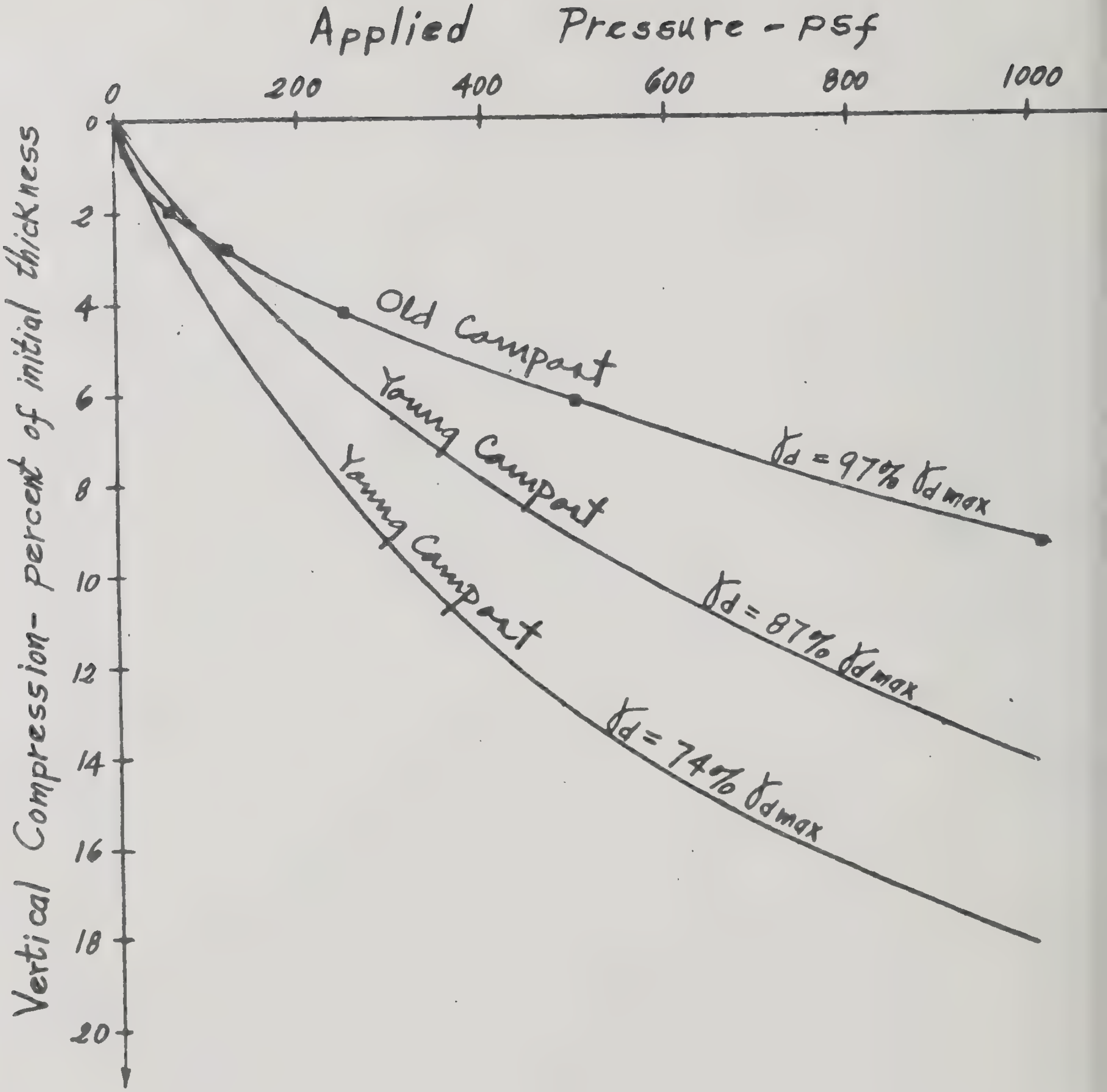
Compost - Sand Mixture (Equal Parts by Weight)
$\gamma_{d\,max}$ = 57 pcf
$w_{opt.}$ = 50%
Old Compost
$\gamma_{d\,max}$ = 42.5 pcf
w_{opt} = 70%
Young Compost
$\gamma_{d\,max}$ = 39 pcf
w_{opt} = 75%
Standard AASHO Compaction
Dry Density - γ_d (pcf)
Water Content - w (%)
60
55
50
45
40
35
30
25
20
0
20
40
60
80
100
120

Fig. B-1



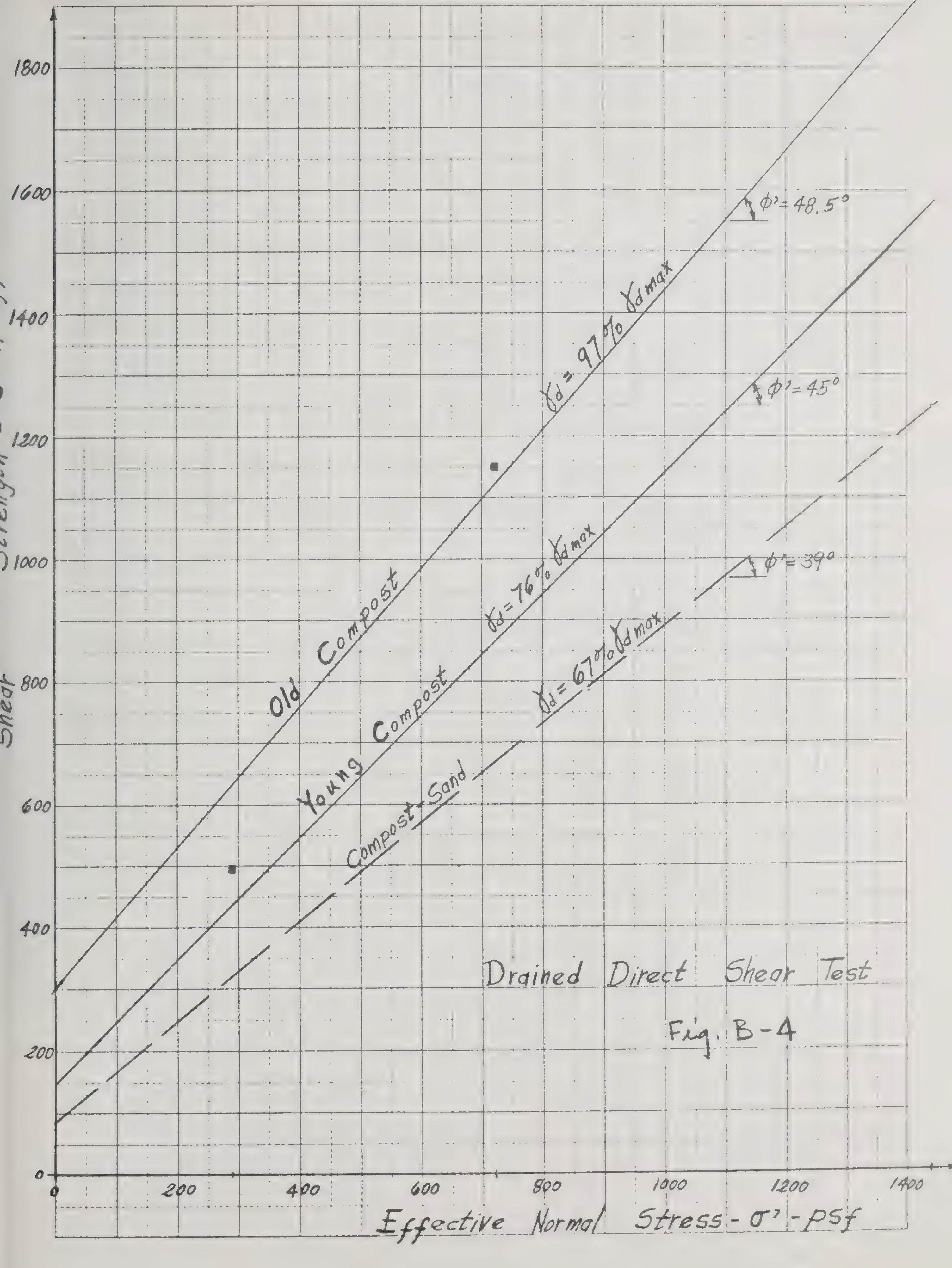
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Permeability, K (cm/sec)
Young Compost $W_l = 77\%$
Compost and Sand $W_l = 28\%$ and $W_l = 34\%$
Young Compost $W_l = 40\%$
Old Compost $W_l = 51\%$
Old Compost $W_l = 51\%$
50
60
70
80
90
100
Percent of Dry Density Refered to
Maximum Dry Density of Standard AASHO

Fig. B-2



Compression Curves for Compost, Mixture of Compost-Sand and Old Compost

Fig. B-3



Drained Direct Shear Test

Fig. B-4

PART B

A PRELIMINARY COMPOST EXPERIMENT AND SUGGESTIONS FOR COMPOST SPECIFICATIONS

by

S. A. Hart, C.E.
Consultant to EIP Corporation

THE DAVIS COMPOST EXPERIMENT

OBJECTIVE

One concept for solid wastes management for the San Francisco Bay Regional Area is to take the refuse and salvage out the glass, ferrous and aluminum cans, and clean newsprint. The putrescible-degradable remainder would be shredded, sewage sludge would be added to it, and "compost" would be made of the mixture. The compost could then be used in the Delta upriver from the San Francisco Bay, as a substitute and supplement to the native peat soils of the Delta islands. The specific use would be for levee-building and for farmland elevation-raising.

There are obviously a number of questions that need to be answered before such a procedure can become a reality. Typical of such questions are:

a. How beneficial would the compost be to the Delta area?

b. What might be the best way to make the compost?

c. Where should the compost be made?

d. What are the materials handling problems year-around, and what are the additional problems in winter?

e. What are the nuisance problems in compost-making?

f. How best might the nuisance problems be overcome?

g. What will the pollution problems be, especially regarding nitrates in the Delta waters?

h. What kind of costs are likely?

Definitive answers to these questions can only be obtained from a pilot-scale demonstration project of perhaps 500 to 1,000 tons of shredded waste per week. However, a better understanding of the above questions, and some direction for pursuing the pilot-scale demonstration, can be obtained from preliminary experimentation. Thus the objective of this present research is to better understand the above questions, and to obtain direction for designing, developing, and promoting the pilot-scale demonstration, so that the final and definitive answers to the questions themselves can be economically and satisfactorily obtained.

WHAT IS COMPOST AND COMPOSTING?

Composting is defined as the sanitary bio-stabilization of organic waste. (Ref. H. B. Gotaas, "Composting", World Health Organization Nomograph No. 31, 1956.) Composting can occur aerobically or anaerobically. Anaerobic stabilization is typically a slow-rate process taking one or more years, and disagreeable odors can occur during the process. Aerobic composting is minimally odor-producing (and the odors that do occur come primarily from anaerobic pockets within the aerobic mass), and it can be quite prompt--a matter of days or weeks depending upon the mechanical assist and the maintenance of optimum conditions.

In essence, microorganisms use the refuse material as a food supply; the microorganisms eat away, grow, reproduce, and cast off lower-energy or more stabilized organic detritus. In aerobic composting, the aggressive metabolic activity results in heat generation, consumption of oxygen, and respiration of carbon dioxide. A typical active aerobic composting mass may develop temperatures in the 50's and 60's, °C. When the readily available "food supply" is consumed, the organic material changes characteristic and composition, and the end product is called "compost." Today at the nursery store, one can buy the end product of bio-stabilization of specific wastes--such as redwood compost, leafmold, and composted steer manure. Compost made from municipal refuse is a very similar product if the non-compostable debris is removed from the finished material.

Considerable scientific investigation has been conducted into the biochemistry of the composting process, including chemical analysis of the raw material and the finished product. Fortunately, much of the involved science can be reduced to an analysis of the carbon: nitrogen ratio. This does not mean that one can make compost from carbon or soot in the chimney and nitrogen in the atmosphere; rather, the carbon in carbohydrates and the nitrogen in fertilizers, amino acids, and protein are the critical components of a compostable material. A typical compostable raw material may have a C:N ratio of 100:1. If moisture, oxygen, and microbial population are correct, this material will compost. In composting, much of the carbohydrate is broken down to carbon dioxide and leaves as a gas; the resultant stabilized "compost" will have a C:N ratio of 20:1 to 40:1.

In measuring the progress of composting, temperature, C:N ratio, moisture content, the composition of the gas or atmosphere of the pile, and the general appearance of the organic mass are used to evaluate the process. In the experiment reported here, a comprehensive program of measurement was not possible, but trends and indications of the above factors were obtained.

THE EXPERIMENTAL SETUP

Professor C. C. Delwiche, Department of Soils and Plant Nutrition, University of California at Davis, was contacted by the EIP Corporation regarding conduct of some preliminary experimentation. Dr. Delwiche has been the University's leading advocate of Delta island peatland preservation, and independently conceived of utilizing municipal compost for reclamation of the islands. Dr. Delwiche was not in a position to conduct the entire preliminary experiment, but agreed to be involved in it, and to have it done at the University of California campus at Davis, if the physical conduct would be done by others.

Samuel A. Hart, C. E., is a consulting engineer who has been involved in composting research, compost utilization, and economic appraisals of the process for over a decade. Dr. Hart was retained

by EIP to conduct the composting experimentation, and to manage the engineering aspects of the project.

The experiment basically consisted of hauling 30 cubic yards of shredded, classified and cleaned-up municipal refuse from an EPA-sponsored facility in Palo Alto to the Davis campus of the University of California.

This dry, shredded, refuse was wetted with digested sewage sludge liquor as it was forked off the hauling truck. The resultant pile or "windrow" was allowed to compost--to bio-oxidize and biologically stabilize until it became finished "compost". The specific approaches to assisting the material to progress into compost are discussed below.

CHRONOLOGICAL AND NARRATIVE COMMENTARY OF THE EXPERIMENT

This first experimentation had to be something of a "cut and try" approach. A chronological description and discussion of what was done and why seems to be the best way to cover the May 1973 activity.

On Wednesday, April 25th, an industrial waste collection truck went to Palo Alto and picked up a load of shredded municipal waste that had the iron, glass, and aluminum removed from it. This was typical municipal waste, and was predominately paper, but contained considerable plastic film, and some cloth, hard plastic, and food scraps. A full 30 cubic yards of material was loaded on at Palo Alto, but the trip to Davis consolidated the waste so that the volume when it arrived at Davis was only 27.8 cubic yards. The weight of the waste was 9690 lbs; based on the original 30 cubic yards, the material weighed 323 lb/yd^3 (11.96 lb/ft^3.)

On Saturday, April 28th, five teen-agers were hired to pitchfork the refuse off the truck and mix it with sewage sludge. The sewage sludge was provided by the University of California from its on-campus treatment plant. 3700 gallons of digested sludge were squirted onto the refuse during unloading, as shown in the photos.

Although a sample of the sludge was taken to the laboratory for analysis, its exact solids content was omitted. It was estimated to be 6% solids. The below tabulation suggests the resulting mixture.

Material	$\%H_2O$	Total Wt.	Solids Wt.	H_2O Wt.
Refuse	15.8	9690	8160	1529
Sludge	94.0	30895	1855	29040
Mixture		40585		30569=75.3% H_2O

In actual fact, two samples of the mixture immediately after making the windrow measured 46.9 and 51.3% H_2O. Considerable moisture from the wetting of the refuse was absorbed by the underlying earth. And from visual inspection after completion, it was felt that too much sludge liquor had been added. One could squeeze moisture out of a handful of the mixture.

A second materials balance was taken on the refuse and sludge--a Carbon:Nitrogen analysis. Using the above weights and C:N data, the following tabulation is presented.

Material	Total Wt.	Carbon Wt.	Nitrogen Wt.	C:N Ratio
Dry Refuse	8160	3810	29.5	129 : 1
Sludge solids	1855	1000 est.	92.8	10.7: 1
Mixture	10015	4810	122.3	39 : 1

The C:N ratio of two mixed samples averaged 66:1, thus the calculated data does not agree too well with the analytic. Regrettably, in this preliminary experiment, there were not enough dollars available to obtain the laboratory control that would have been desirable.

The week of April 30-May 4 was the first week of actual composting, and the windrow needed to be turned. An attempt was made to do it with hoe and pitchfork. This was completely impossible. The mixture was so wet it almost had the consistency of wet paper-maiche. Only about 10% of the pile was turned in 12 man-hours of work. Therefore, on May 7th, the University's backhoe was used to turn the remaining 90% of the pile. This was very effective in moving the windrow, but

Fig. 1 Refuse unloading with sludge tanker in background

Fig. 2 Applying the sludge to the refuse.

complete mixing and aeration was not obtained. However, this intitial breaking up of the pile helped very much, and made subsequent manipulation much more satisfactory.

Fig. 3 Use of the Backhoe to make the first turning.

Odors during the first week were more typical of digested sewage sludge than anything else. There was an odor in the vicinity of the windrow, but it was not overly objectionable or powerful, and was not evident 100' from the pile. When the pile was being turned--by hand and by backhoe--a reasonably strong anaerobic and disagreeable odor emanated. After a few minutes near the pile the odor lost its noticeableness, but it clung to one's clothes and was noticed by others away from the experiment.

It was obvious that too much moisture had been added to the refuse in the original sludge mixing, in spite of the fact that the C:N ratio was still high (66:1 after mixing). It would appear that at least a partial dewatering of the sludge would be desirable prior

to mixing it with the milled refuse--if composting is the prime objective. However, when disposal of the wastes is recognized as the prime objective, the balance between sludge and refuse can be secondary to the disposal of the two quantities of waste.

Although the wetted refuse retained the sludge liquor well, some drainage did occur. This saturated the underlying native earth, and made for difficulty in making the first turning. Additionally, it is certain that this would create odor and fly breeding problems under some circumstances. Therefore, it also appear desirable that any windrow composting be done on a concrete or asphalt slab. It is noteworthy that such a finding was learned on this initial experimentation, and serves to guide the planning and design of the pilot-scale demonstration proposal.

The week of May 14 - 18 was the second week of composting. The turning difficulty in this experiment can be translated into costs and technical problems when large quantities of waste are to be composted on a daily basis. Therefore, a decision was made to investigate a second approach to composting, with a part of the volume of the experimental waste. Specifically, it was conceived that shredded refuse plus its mixed sludge could be laid down in a 1' or 2' thick blanket, and be covered with a 3-4" sheet or top dressing of finished, high-grade, screened compost for appearances sake. If this blanket and top dressing were kept moist, it would remain aerobic and compost itself over a period of 4 to 6 months, the result being "in situ composting". At the end of six months, a freshlayer of shredded refuse and sludge, covered with yet another top dressing of high-grade screened compost could be placed over the first layer, and it too would compost. This layering of refuse that would change to compost could be done on the levee banks, or in the Delta island interior. Over a period of several years, a significant volume of waste material would be properly managed, the composting would proceed with efficiency and economy, and the resultant land or levee would be benefitted equally to conducting the composting in another manner.

To test this concept, approximately half the original windrow was placed in 6½' diameter rings, as shown in Fig. 4.

Fig. 4. Rings of composting waste for <u>in situ</u> bio-stabiliazation

The specific layout of the rings is:

1' thick, a loose blanket
1' thick, compacted to simulate consolidation from traffic
2' thick, loose blanket
2' thick, consolidated
3' thick, loose

Because no high-grade screened compost was available as a top dressing, these rings were left uncovered. However, a small ring was covered with some locally available leafmold, Fig. 5.

Fig. 5. Model of <u>in situ</u> composting, with leafmold top dressing

As a final comment to this second turning activity, it was noted that this second turning could be done very satisfactorily with a hoe and pitchfork. This was in marked contrast to the problem of the first turning.

The week of May 21-25 saw the residual pile turned for the third time. This third turning was also easily accomplished by hand. The odor level in making the second turning was less than in the first turning, but was still evident and rather disagreeable. The odor of the third turning was quite minimal, and although not truly pleasant, was not considered disagreeable.

The two turnings of the ringed waste, and the three turnings of the remainder, plus the biological degradation that has already taken place, has effected a considerable reduction in volume. Of the original 30 cubic yards of refuse brought to the campus, the volumes at the end of the week were:

1' loose ring, sunk to 11" high	=	1.15 cu yards
1' compacted ring, sunk to $11\frac{1}{2}$"	=	1.21
2' loose ring, now 20" high	=	2.11
2' compact ring, now 22"	=	2.32
3' loose ring, now 28"	=	2.96
Residual pile, approx. volume		13.33
Total		23.08 cu yards

This is a reduction of 23% in volume to date.

The week of May 28-June 1. It appeared that the rings and pile were becoming quite dry. Specific moisture content determinations were not easily made, but a part of the "cut and try" experimentation included the need to maintain moisture, and to appraise the possibility of sprinkler irrigation of the blanket or the windrow. A wetting of the rings and pile was therefore made. The data on this, plus the temperature data on the rings and pile is tabulated below.

Temperature and Irrigation Data

Unit	May 3	May 10	May 17	May 24	May 31	Total H_2O	Inches per foot
Windrow	38°C	48	45	64	65	3.4"	1.4
1' loose	-	-	50	45	40	2.4	2.4
1'compact	-	-	41	48	47	3.4	3.4
2' loose	-	-	64	46	60	11.6	5.8
2' compact	-	-	54	55	59	6.0	3.0
3' loose	-	-	60	55	57	5.3	1.7

In retrospect, the irrigation was perhaps not as warranted as originally thought. It would have been more desirable to have purchased some redwood bark compost to cover the tops of the rings to prevent their drying out, then to merely have watered them lightly. On the other hand, the turned windrow is drying out excessively from the turnings, and it really does have to be kept moistened or else much of it is becoming so dry that it will not continue to compost. However, the irrigation was useful in that it showed the absorbtion capacity of the composting material is tremendous. Nor does the irrigation make the loosely-packed rings consolidate further or faster. Thus it can be conjectured that winter rains will have no detrimental effect on a blanket of in situ composting material.

SECOND MONTH'S ACTIVITY

During June 1973, the actively-turned pile received its 4th and 5th turnings. A shredding-screening test was made on a portion of the 4th-turned compost. Approximately 50% by weight, about 33% by volume, of the material went throught the 3/4" shaker screen of the soil shredder. This machine has a hammer mill prior to the screen, and considerable of the plastic film was torn into small enough fragments to go through the screen. However, the screened material still looked quite good. It was not truly finished compost, in that when put into a container, it slightly reheated. The shredded material was quite brown, light in weight, and friable with a faint soil-like odor. Some of the material was used to cover the top of the ring of in-situ composting material. It is shown below.

Quality of the shredded and screened compost

Some of the material was taken to San Francisco where EIP will have tests made on the structural strength of the material.

The plastic film problem deserves special mention. Plastic film was not at all obvious in the original shredded, air-classified, dry refuse. When the sewage sludge was added to the refuse, the paper absorbed the moisture, which the plastic film did not. The film thus became more visually evident. As composting has progressed, the film has become ever more evident. Probably the film amounted to only 1-2% of the original refuse by weight and volume, and today it is still a minimal component by weight and also by volume. However, the "surface area presentation" is extremely evident. The screening operation (preceeded by the shredding of the hammer mill) does tear some of the plastic so that a bit of it goes through the screen, but in reality, the screened compost does look good. The scalpings from the screening contained a significant amount of plastic, and although this was repiled for composting and is reheating, the plastic film will still have to be handled at a later date. It is thus apparent that the plastic film problem will require specific resolution over the long-term.

One possibility is to do the compost screening at the completion of composting--after 6 to 8 turnings and several months. The scalpings should then be primarily plastic film, refractory material, and contain a minimal amount of water-containing organic matter. These scalpings could well have a high heat value and be incinerated. Alternatively, the scalpings could be buried beneath the high-quality compost. This latter is a viable solution if in-situ composting should be considered. In any event, plastic film becomes ever more evident as stabilization reduces the presence of the paper, garbage, and other biodegradable components of the refuse.

Paper blowing is a second problem that should be commented upon. The original wetting of the refuse was effective in weighting down the paper component so that blowing was not a problem during the first stages of composting. Even today, paper itself is not serious, but as the paper biodegrades, it leaves the plastic film. During turning of the material, the film now tends to blow badly. It has been necessary to move out to the adjacent fields to retrieve that film. It is absolutely evident that a structure will be necessary in which to do mechanical turning of the compost.

THIRD MONTH'S PHYSICAL ACTIVITY

The turned compost pile received its 6th turning during July. It had been intended to also do a 7th and final turning, but there was no time to do it, so this will wait until later. All rings and the turned pile were irrigated twice. Temperatures have been taken, and there continues to be significant biological activity in all piles and rings, with temperatures generally in the 38-44°C range (around 100°F). However, the 1' and 2' compact rings run 3 or more degrees hotter than their loosely-placed counterparts. This, plus the general observation that the compact-placement rings accept the irrigation water better (without wet and dry spots and without premature leakage), and with an intangible but apparent better appearance of the composting mass indicate that in-situ composting occurs better if the waste is placed in a somewhat compact condition.

Bulk density testing had been attempted in May and June, but the results were erratic and unreliable. The technique was refined through two additional test in July, and reasonably reproducable results were obtained. There results are:

Bulk Density in lbs dry solids/ft^3

Sample	July 2 test	July 18 test
1' loose	7.1	10.0
1' compact	13.7	14.8
2' loose	7.9	9.4
2' compact	16.0	16.3
3' loose	11.4	10.6
Main Pile	10.6	12.9

It is thus realistic to believe that the composted dry solids, when placed, will average someplace between 12 and 15 lb/ft^3.

And finally, using the bulk density data and the known volume of the rings and pile, a calculation was made on the loss of organic material due to composting. Specifically, between 30 and 35% of the original dry solids weight of the refuse and sludge has been lost due to biological attack, conversion, and stabilization.

AN IMPORTANT COMMENTARY OR DISCUSSION POINT

During July, Alan Carlton, a consultant to EIP, visited the experiment. His knowledge of Delta agriculture brought out a point that has not previously been recognized and must now be seriously considered.

He pointed out that due to natural oxidation of the delta peat soil, the loss in topsoil is 1-3"/year. (This is a fact we knew.) This is manifested by the fact that the "ash" content of virgin peat is only about 10%, but the "ash" content of the delta topsoil is about 30%. That is, oxidation of the peat soil removes the organic material and leaves the residual mineral ash behind, thus concentrating it in the topsoil. Further, because of this 1-3" loss of topsoil each year, each Spring plowing "turns up" and exposes a 1-3" sheet of virgin peat which gets mixed in with the residual topsoil.

The importance of this continual oxidation as it relates to compost utilization is the ever-greater emergence and presence of plastic film. Plastic film has already been recognized to be a most unwanted component of the refuse and of the compost. Now it is brought home that the film will be an impossible constituent of the compost when applied to the Delta. Specifically, the compost will oxidize and thus will be lost. But the plastic film will not similarly be oxidized and lost. Rather, like the mineral or "ash" content of the original peat soil, it will become an ever more concentrated component of the residual material.

The message seems clear--a very high percentage of the plastic film will have to be removed before, during, or after the composting operation in order that the compost can be placed and utilized in the Delta. There must not be a gradual surfacing of excessive plastic film as the compost oxidizes and leaves behind only plastic film.

SUGGESTED COMPOST QUALITY SPECIFICATIONS

INTRODUCTION

Most research on compost quality has been concerned with the degree of stabilization required for use on the land as related to crop productivity in the year of application, or in the subsequent year. In the case of compost for the Delta Islands, immediate use is not the issue, and compost quality must be related to its environmental impact, relationship to wastes management, and agricultural viability.

The below specifications thus relate to the physical, chemical, biological, and pollutional characteristics rather than to the agricultural worth of the material. These quality criteria are tenative, and relate to known facts about compost. But it should be recognized that a modification of the specifications will probably be needed, based on the results of the proposed 3-year pilot study.

THE SPECIFICATIONS

The quality of the composted waste material to be placed in the Delta Islands shall conform to the following limits:

1. Dry Weight Bulk Density The bulk density of the dried compost solids, without any moisture addition, shall be no greater than 25 lbs/ft^3, when tested by means of the Standard Proctor Compaction Cylinder test.

Discussion: The University of California, Davis, research on composting, conducted this year (1973) has shown the dry solids bulk density of compost to be 9-16 lbs/ft^3. The bulk density of the dried compost solids, when compacted in a Standard Proctor Compaction Cylinder Test, without added moisture, runs no more than 20 lb/ft^3--unless there is extraneous soil or sand mixed with the organic compost. Thus the real purpose of this specification is to insure that if compost is paid for by finished tonnage, that tonnage is not unfairly upped by mixing in dirt.

2. Particle Size Limits All compost particles shall pass through a 3/4" square opening screen, and at least 50%, but not more than 95%, by dry solids weight, of the compost shall pass through a 3/8" square opening screen.

Discussion: This specification is also partially conceived to prevent adding soil (or gravel particles larger than 3/8".) However, firstly, it is recognized that there should be a maximum particle size. The University of California compost was screened through a 3/4" sieve and the appearance is reasonably acceptable. Some 2-year old Houston compost was also sieved, apparently through a 1/4" sieve, and its appearance is much better. But the compost is not intended for home gardening, and does not need to be of perfect appearance, the 3/4" sieve therefore appears to be acceptable. The reason that at least 5% of the compost needs to be retained on the 3/8" sieve is so that the test of Specification 3, relating to plastic film, can be made.

3. Maximum Plastic Film Content Not more than 1%, by dry solids weight, of the compost passing the 3/4" screen and retained on the 3/8" screen, shall consist of plastic film, or hard plastic of any color other than black or brown.

Discussion To explain this requirement, one must first understand the phenomena of peat soil--or humus or compost--disappearance in the Delta Islands. Each year when a Delta Island farmer plows his land, he turns over about an 8" plow layer. 5 to7" of that is the previously worked soil, but the bottom 1 to 3" is always a virgin peat. Thus during each crop year, the beginning 8" of topsoil shrinks to 5 or 7". The shrinkage or loss is due to the oxidation of the highly organic soil. This oxidation loss of the organic content is proven by the fact that the ash content of the virgin peat is only about 10%, but the ash content of the topsoil is 30 to 40%. The organic content has oxidized off, leaving the residual ash to become ever more concentrated.

This same situation will occur with compost, and one of the things left behind to ever increase in concentration will be the plastic film. The University study of composting was most enlightening; plastic film was noted within the raw refuse and sewage sludge mixture, but it was in no way an obvious component. As composting progressed, the nondegradable plastic film became a more and more obvious--and visually objectionable--part of the compost. It is

felt that the content of the plastic film must be kept to a minimum, and 1% of the material retained on the 3/8" screen appears to be that reasonable minimum.

4. Biodegradability The compost shall be biologically well-stabilized. The measure of the compost stability shall be that firmly-packed, adequately and properly moistened compost, when placed in an insulated container of at least 1-cubic foot capacity, within a room maintained at least 18°C, shall not heat up more than 5° C maximum at any point within the cubic foot, in a 24-hour period.

Discussion: There are several ways to measure the degree of stabilization of compost: 1) appearance, 2) odor, 3) final drop in temperature, 4) degree of self heating capacity, 5) remaining amount of resistant decomposable matter, 6) rise in redox potential, 7) oxygen uptake, 8) growth of Chactomuim gracile, 9) and the starch test.[1] In practice the first three are what the operator would use to "feel" when the compost is ready. The fourth method-reheating capacity-has been chosen, however, as the best quantitative indicator of readiness.

It is proposed that the test consist of taking reasonably moistened material and packing it (by hand) within a polystyrene "ice chest". The lid would be put on and 24 hours later a thermometer would be put into it. If biological activity is significant, the temperature would rise significantly. A 5°C temperature rise is not very much, and would appear to indicate considerable stability to the compost. It is recognized that this specification, probably more than any of the others, will be refined during the pilot study. However, it is presently as valid, quick, reproducible, and meaningful as anything else could be to measure relative stability and thus acceptability of the compost to be transported to the Delta islands.

5. Salt and Leachate Content The compost shall not contain excessive amounts of salts or other soluble materials. Specifically, the quality of the compost shall be such that the electrical conductivity (EC) of an extract made from a filtrate using 10 ml water per gram of dry solids compost, shall not exceed ________ millimhos per centimeter (mmh/cm.)

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1 Composting, Clarence Golueke, Rodale Press, 1972.

Discussion: One of the critical problems in using compost in the Delta Islands is the possible pollution of the Delta waters due to leaching of irrigation water, and rainfall, through the placed compost. There is no answer to this as yet, both from a Regulation standpoint, and from the practical point of whether leachate quality has an effect upon the agricultural productivity of the land. Thus for the present, the quantity of allowable leachate is unknown, and must be determined from some University analysis.

However, the possible technique for determining the quantity of leachate is straightforward, and is patterned after the procedure for determining the salt content of a soil. Specifically, a definite quantity of water is mixed with the material to be tested, (Soil or compost), and the extract is measured with an electrical conductivity meter, the salt content of the filtrate being related to the millimho/cm conductivity of electricity through the slightly saline filtrate water. This same procedure is proposed here, although at present no specific value is given. However, as a comparison, it is known that fresh dairy manure has an electrical conductivity of its extract of 2 mmhos/cm, when 10 ml H_2O are used per gram of dry solids. One would expect the conductivity of a compost extract to be less (less in the compost) than that for manure where salt is a component of the diet.

6. General Nuisance Limitations The completed compost shall not be so dry as to create dust when handled. Nor shall the compost be so moist that any drainage occurs. The odor shall not be other than can be described by "vacuum cleaner dust" or "freshly turned soil".

Discussion: The moisture content should be to where the material is basically moist enough not to cause dust, but not so wet as to cause drainage liquor, in a pile or draining from a truck. Actually, in the normal situation, the compost will tend to dry out more than to become excessively wet. In any event, moisture problems need not be serious with compost.

Odors also need not be serious. Fresh dry refuse has an unmistakable "garbage" odor and sewage sludge can smell like anything from sewage to a tarry, sweet, non-objectionable material. However, as composting proceeds the odor changes to that of vacuum cleaner

dust, and a completely ripe, well-cured compost has the very pleasing odor of freshly turned earth.

SUGGESTED OPERATING SPECIFICATIONS FOR COMPOSTING

INTRODUCTION

One of the great concerns of the local citizenry is that wherever the actual composting is conducted, it be conducted without nuisance to nearby residents. It is therefore appropriate that there be operational performance specifications. The following recommendations are designed to eliminate, or to at least minimize the potential hazards of nuisance and pollution from the composting operation.

It is important to recognize that these operational performance specifications are not absolutes. They will not positively prevent nuisance under all conditions, but they contain penalty provisions that will quickly make it uneconomic for the composting contractor to operate in anything but a nuisance-free manner. There is an analogy; most cities have 25 mph speed laws. These do not absolutely control everyone from travelling faster than 25 mph, but the law makes it uneconomic to travel faster than the posted speed limit. So too with the following operational specifications; they cannot positively control all nuisance or hazards of operation, but violation carries a financial penalty that will cause compliance to nuisance-free operation.

Each performance specification is spelled out in pseudo-ordinance or pseudo-contract form. A discussion section follows each specification which explains the rationale for the specification, and gives ideas on how the requirement might be met.

1. Prevention of Odors In conducting the composting operation, the Contractor shall perform in such a manner that objectionable odors do not occur. The measure of objectionableness shall be vested in the local citizenry, aided by municipal staff appraisals and scientific tests as are appropriate. The penalty for causing

objectionable odor conditions shall be $200/day for each day of objectionable odor production, and any fines shall be paid to the city.

Discussion: Odors from the composting operation will occur only when the refuse-sludge mass becomes anaerobic in itself, or when the anaerobic condition is being combatted by extensive turning and aerating. The anaerobic condition will develop only if the incoming refuse-sludge mixture is too wet and compacts, or the windrow turning equipment breaks down so that the intervals between turnings is too infrequent. It is also true that on a completely still (usually hot and humid) day, an otherwise too-dilute and non-objectionable odor condition may turn into an odorous situation.

The control of odors is obvious; the contractor must control the moisture content of the refuse-sludge mass as it turns to compost, and there must be adequate standby equipment available to keep the windrows turned on schedule. There also needs to be provision for extra turning when an incipient anaerobic-odorous condition is seen to be developing, and compost turning must also be conducted at times when air movement is away from areas of possible complaint.

The specification suggestshow odor measurement and penalty impostion might be done. Regrettably, gas and air analysis by even the best of today's scientific procedures and equipment has not been effective in quantifying odor components at the "parts per trillion" level--the level that can be detected by the human nose. However, a single citizen's complaint of odors may be a biased situation, and automatic penalty assessment based on one or a few chronic complainers is probably not in the best interest of anyone. It is therefore proposed that if or when there is a citizen's complaint, it be checked out by the community's Public Works and police departments. (Calls usually are first received by the Police). Upon the finding of a legitimate odor, it is recommended that the Contractor be immediately fined the $200/day, and be made to explain the situation. After all, he too knows there is an odor condition because he is right in the middle of it. The immediate fining and requiring a report on the cause should go a long way in preventing reoccurance. It is also suggested that the Contractor's report be duplicated and be sent to each complaintant; this would be a way to involve the local citizenry in the operation, and in understanding the difficulties.

2. Preventing Blowing Paper, Litter, and Dust Contractor shall operate the composting operation within an enclosure such that paper and other litter shall not be carried off the premises. Nor shall dust and other particulate matter, as measured by dustfall jars or other devices within 100 feet of the composting enclosure measure more than 25% more dustfall than similar devices 1000 feet from the enclosure.

Discussion: It is absolutely mandatory that the composting operation not create a waste paper and litter problem in the neighborhood. To prevent blowing paper, the composting operation needs to be conducted within an enclosure. For economy and overall effectiveness, it is proposed that the enclosure be 1" poultry netting, roof and sidewalls, with the roof being a cable-supported structure. 1" poultry netting will, of course, be effective in containing larger particles, although some small particles and dust can escape. However, particles less than 1" in size do not generally have favorable aerodynamic properties (confetti does not really travel well.) Further, such quantity of uniform-sized litter will not be especially obvious, if it exists at all.

Similarly, the dustfall measurement will be easily met if the Contractor maintains the compost windrows in the moist condition which is also required for optimum rate composting.

3. Runoff Water Control Contractor shall capture all rainfall or other free water falling on or occuring on the paved composting yard, and shall recycle or otherwise properly dispose of said water in order to prevent surface or underground water pollution.

Discussion: It is inferred that composting occurs on a paved yard--this is correct, and such paving is absolutely mandatory to prevent fly problems, prevent anaerobic conditions from developing in the base, and prevent infiltration of polluted water. For a 20-year project, the paving could be concrete, like a heavy-duty highway. Probably for the three-year demonstration project, an ashphaltic or bituminous paving is all that can be justified. Regardless, the windrows will cover only 50-60% of the yard, so rainfall will result in a runoff.